TECHNOLOGICAL HANDBOOKS.

EDITED BY H. TRUEMAN WOOD,

Secretary of the Society of Arts.

THE PRINCIPLES OF GLASS-MAKING.

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THE

PRINCIPLES OF GLASS-MAKING,

BY

HARRY J. POWELL, B.A.,

TOGETHER WITH TREATISES ON

CROWN AND SHEET GLASS,

BY

HENRY CHANCE, M.A.,

AND

PLATE GLASS,

BY

H. G. HARRIS,
ASSOC. M. INST. C.E.

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PREFACE.

THE different branches of the manufacture of glass are of so distinct a nature that it has been thought desirable to secure the services of gentlemen who have had practical experience of the more important divisions of the business in the preparation of this handbook. By this means it is hoped that a fuller and more accurate account of the details of the various processes has been insured than might perhaps have been the case had the volume been the work of a single author.

The first part of the work, by Mr. Powell, of Whitefriars Glass Works, is introductory to the whole. It treats of the general principles of the manufacture, methods of analysis, raw materials, apparatus, tools, &c. It also includes the more special divisions of the manufacture of "hollow ware" and "glass mosaic" or stained and painted glass. The second part, by Mr. H. Chance, of Birmingham, is confined entirely to the manufacture of crown and sheet glass; and the third part, by Mr. Harris, the Secretary to the British Plate Glass Company, to the manufacture of plate glass.

An appendix contains the examination papers set in the subject of glass-making in the Technological Examinations of the City and Guilds Institute, and a second appendix gives a list of works on glass for the use of students in these examinations and others. This list does not profess to be a

complete bibliography of glass-making ; it is only intended as a guide to those who wish to extend their studies beyond the necessarily narrow limits of an elementary handbook.

The Publishers have to acknowledge their indebtedness to Messrs. Spon for permission to reproduce many of the illustrations used in the excellent article on Glass in the Encyclopædia published by that firm.

H. T. W.

THE PRINCIPLES OF GLASS MAKING, AND THE MANUFACTURE OF HOLLOW WARE.

BY H. J. POWELL, B.A.

INTRODUCTORY.

A PRACTICAL knowledge of the manufacture of glass is generally acquired through apprenticeship, and the study of hereditary recipes. There is danger that the proficiency, which may be thus attained, will be based on a groundwork of "rule of thumb" rather than of science. The want has often been felt of a work illustrating the present condition of the manufacture, and at the same time defining the principles upon which experience has proved the several processes to be based. Such a work should be valuable as a guide amidst disjointed recipes, as well as a basis for the accumulation of new facts and methods. It must, however, be remembered that a manual can never supply the place of experiment and experience.

The order of contents observed in this division of the work is as follows :—

1. The discovery of the constituents of a given sample of glass.
2. The chemical and physical qualities of glass.

3. The raw materials used in the manufacture of glass.
4. The means employed for utilizing the qualities of glass for manufacturing purposes, namely, crucibles, furnaces, and auxiliary furnaces.
5. The special treatment of the several branches into which the manufacture is divided; namely,
   The manufacture of hollow ware, and the processes by which decorative effects are obtained.
   The manufacture of flat, white, and coloured, glass for glazing, and the manufacture of optical glass.

CHAPTER I.

Analysis of Glass.

THE word "glass" suggests a substance which is transparent, solid, hard, and brittle. This description is far from complete, and will require considerable amendment. The manufacturer must have a more accurate acquaintance with this substance, and if a specimen be handed to him for imitation he must be able to determine of what the specimen is composed, and how a similar material can be produced. Part of the specimen must be subjected to chemical analysis, both qualitative and quantitative. The processes employed in the analysis of glass differ in some respects from those of simple analysis owing to the virtual insolubility of the material in all acids except hydric fluoride. It will not be out of place to indicate a simple method of procedure, omitting such particulars as are to be found in elementary works on practical chemistry.

The Discovery of the Constituents of a given Sample of Glass.

Reduce a fragment of the glass to impalpable powder, and divide the powder into five parts. One of these parts should be expended in preliminary tests, with the blow-pipe flame, using charcoal and borax-beads as carriers. By these tests the presence or absence of certain metals may be determined. Of the remainder of the powder, set apart two parts for the qualitative, and two for the quantitative examination.

Qualitative Analysis (Part A).

Mix one part with about four parts of a mixture of the anhydrous sodic and potassic carbonates; the weights of the ingredients being in the proportion of 53 of the sodic to 69 of the potassic carbonate. The mixture of glass and carbonates is placed in a platinum crucible and heated until the fusion is complete, and bubbles are no longer given off. The crucible is removed from the flame, and the contents, when cold, are placed in a porcelain dish and treated with dilute hydric chloride, a gentle heat being applied until everything is dissolved except certain white flakes, which remain floating in the liquid. If the preliminary tests have indicated the presence of lead in the glass, the contents of the crucible should be treated with hydric nitrate instead of hydric chloride. Separate the white insoluble flakes from the liquid by filtration; the liquid which passes the filtering medium and is known as the filtrate, holds in solution all the metallic oxides present in the glass under examination. What metals are present will be discovered by the ordinary analytical tests; it will, however, be useless to look for sodium and potassium, as the carbonates of both these metals have intentionally been added. Wash thoroughly, and dry the white in-

soluble flakes remaining on the filtering medium. Place the dry powder detached from the filtering medium, in a platinum dish, and warm gently with an excess of perfectly pure hydric fluoride. The substance combines with the fluorine of the hydric fluoride and passes off in a gaseous form, leaving no residue. The substance is pure silica.

Qualitative Analysis (Part B).

Place another part of the powdered glass in a platinum dish. Cover the powder with pure hydric fluoride, and stir into a thin paste with a platinum wire. Evaporate the paste to dryness over a water-bath, and to the dry mass add a small quantity of hydric chloride. Evaporate once more to dryness, in order to expel the volatile fluorides and silicic fluoride, and dissolve the residue, when cool, in a large quantity of distilled water. Into this solution pass hydric sulphide gas for a considerable time, filter off any precipitate, boil the filtrate in order to expel the excess of hydric sulphide, and reoxidize with a few drops of hydric nitrate. Add ammonic hydrate, filter off any precipitate, and boil the filtrate until it is highly concentrated. Add a strong solution of ammonic sesquicarbonate, then ammonic hydrate, and allow the mixture to stand. Filter off any precipitate. The filtrate may retain potassic and sodic chloride together with certain ammonic salts. Evaporate the liquid to dryness, and ignite carefully until every trace of ammonia has been dispelled. Dissolve the residue in a small quantity of distilled water, acidulated with hydric chloride, and divide into five parts—*a*, *b*, *c*, *d*, *e*.

(*a*) A yellow precipitate, when platinic chloride is added, indicates potassium.

(*b*) Add hydric tartrate and stir with a glass rod. If potassium be present, and the solution be sufficiently concentrated, a crystalline precipitate of potassic tartrate will be found.

(*c*) Add hydric silico-fluoride. A white opalescent precipitate indicates potassium.

(*d*) Add hydric potassic metantimoniate. A white crystalline precipitate indicates sodium.

(*e*) Evaporate to dryness, mix the residue with alcohol, and ignite. A yellow flame indicates sodium. Examine the flame through a thick sheet of dark-blue glass. If potassium be present the characteristic violet flame will become visible, even in the presence of the intense yellow of the sodium flame.

Quantitative Analysis.

The qualitative analysis will have discovered the presence of silica, together with certain metallic oxides, but the quantity by weight of each substance in a given weight of the glass remains to be determined. Dry the remainder of the impalpably powdered glass at 100° C. and place it in a desiccator to cool. Weigh a convenient quantity, and place it in a shallow platinum dish, moisten the powder with pure hydric sulphate, and place the platinum dish on a leaden or platinum tripod in a leaden box, having previously covered the bottom of the box with a stiff paste made with powdered fluor spar and hydric sulphate. Cover the box loosely with a sheet of lead, and place it where fumes can pass away without causing injury or discomfort. A gentle heat is applied and continued until the glass is completely decomposed. When decomposition is complete, which will be in from four to five hours, the platinum dish with its contents is placed in a larger dish of the same metal, and pure hydric sulphate is added drop by drop in more than sufficient quantity to convert all the metallic oxides into sulphates. The outer dish is heated in order to drive off from the mixture the volatile fluorides and silicic fluoride, and the mixture is subsequently ignited in order to expel the excess of free

hydric sulphate. The residue, when cold, is moistened with hydric chloride, diluted with distilled water, and gently warmed. If lead and barium be present in the glass a white deposit of the mixed sulphates of these metals remains undissolved. If this be the case, concentrate the liquid by evaporation, add an excess of hydric sulphate, and continue the application of heat until the hydric sulphate itself begins to volatilize. By this treatment the hydric chloride is expelled and the sulphates of lead and barium are entirely precipitated. The strongly acid mixture is allowed to cool, distilled water is added, and the clear solution (*a*) is separated from the precipitate by filtration. The precipitate still remaining on the filtering medium is washed first with water acidulated with hydric sulphate, and then with alcohol: the filtrate in each case being added to the solution (*a*). The precipitate and filtering medium are placed in a small glass beaker and a solution of ammonic sesquicarbonate is added in order to convert the sulphate of lead into carbonate. This process requires considerable time and a low temperature. The whole mixture is transferred to a filter, and the solid residue is washed first with solution of ammonic sesquicarbonate, and then with distilled water. The carbonate of lead is now separated from the sulphate of barium by careful treatment with hydric acetate, which dissolves out the carbonate of lead, but leaves the sulphate of barium undissolved. The residue is well washed, dried with the filtering medium at 100° C., and ignited in a porcelain crucible. The porcelain crucible when cool is transferred to a desiccator. The weight of the crucible and its contents, less the ascertained weight of the crucible together with that of the ash of the filtering medium (the weight of the latter having been ascertained by igniting and weighing an equal quantity of an identical material) gives the weight of *sulphate of barium*. The clear solution containing the carbonate of lead dissolved in hydric acetate is evaporated with an excess of hydric sulphate until the

latter begins to volatilize. By this treatment the lead is reprecipitated as sulphate of lead. This precipitate is separated by filtration, and dried, ignited, and weighed in the same manner as the sulphate of barium. The acid solution (a), separated by filtration from the sulphates of lead and barium, contains as sulphates whatever other metals are present in the sample of glass. These metals must be separated by the ordinary methods. In order to determine the weight of silica another part of the powdered glass must be used.

CHAPTER II.

The Chemical and Physical Qualities of Glass.

THE analysis of every sample of glass discovers the presence of the substance known as silica. For this reason silica ($SiO_2 = 60$), more accurately termed the dioxide or anhydride of silicon, is recognized as the essential constituent of glass. There are many varieties of glass, which differ one from another in the metallic oxides associated with the silica, every true glass containing at least two metallic oxides. The oxides which occur most frequently are those of potassium, sodium, lead, calcium, barium, aluminium, and magnesium. Traces of other metals are found which are present as impurities, or have been added to produce effects of colour. Analysis determines the quality and quantity of the constituents of glass, but throws little light upon the manner in which they are associated. It is known that the association of the silica with the metallic oxides is effected by heat, but the relationship by which they are bound together requires further investigation. Taking the result of an analysis of flint or lead glass as an instance, namely, silica 53·17,

potassic oxide 13·88, plumbic oxide 32·94, the problem to be solved is, what chemical or physical changes developed by heat have converted these ingredients into an amorphous transparent body? It sometimes happens when red lead (Pb_3O_4) is subjected to prolonged heat in an ordinary fire-clay crucible, that the oxide of lead finds its way through the bottom of the crucible by uniting with the free silica in the clay to form silicate of lead. If sand (the commercial representative of silica) be mixed with red lead in various proportions and the mixtures be heated, silicates of lead will be formed differing from each other in quality according to the difference of the proportions of the ingredients. Potassic carbonate consists of potassic oxide associated with carbonic anhydride, and potassic sulphate of potassic oxide associated with sulphuric anhydride. If potassic carbonate be heated in a platinum crucible until it becomes perfectly fluid, and dry sand be gradually introduced, an effervescence will be set up and a new substance will be found in the crucible composed of various potassic silicates. The nature of the disturbance caused by the introduction of the sand may be ascertained by placing the platinum crucible containing the fluid carbonate at the bottom of a deep vessel, adapted for the collection of the evolved gas, and subjecting this gas to the ordinary tests for carbonic anhydride. By simple experiments of a similar character it is found that sodic, calcic, baric, and other silicates may be obtained by the indirect decomposition of the respective carbonates caused by the combined action of heat and silica. It has also been found that the energy excited in silica by heat is sufficient to decompose the sulphates of sodium and potassium, the decomposition being accompanied by the evolution of sulphuric anhydride, and the formation of sodic and potassic silicates. The heat required for the expulsion of the sulphur in the form of sulphuric anhydride is very intense; but if the sulphate be mixed with about one-tenth of its weight of charcoal or coal-dust, which robs the sulphate of a part of its oxygen to form carbonic

oxide, the sulphur is expelled in the form of sulphurous anhydride and at a lower temperature. These experiments supply sufficient data for settling the question as to the constitution of flint and of the other varieties of glass. If potassic silicate results from the fusion of sand with a substance containing potassic oxide, and plumbic silicate from the fusion of sand with an oxide of lead, it will not be too much to assume that if the same ingredients be simultaneously fused, the result will be a mixture of the same silicates. Flint glass is therefore regarded as a mixture of the silicates of lead and potassium; Bohemian glass, which is made up of silica with the potassic and calcic oxides, as a mixture of the silicates of potassium and calcium; and Plate or Sheet glass, the constituents of which are silica and the calcic and sodic oxides, as a mixture of the silicates of calcium and sodium. In fact, every variety of true glass is found to be a mixture of at least two metallic silicates. The word "mixture" is used in preference to "compound," as there is difficulty in determining the molecular composition of constituent silicates. The difficulty is caused, in great measure, by the fact that silica unites with the same metallic oxide in several different proportions, which is well illustrated by the formulæ of the silicates of sodium (Na_2O, SiO_2 : $2Na_2O$, $5SiO_2$: Na_2O, $3SiO_2$: Na_2O, $4SiO$). Experience, however, has ascertained a proportion of ingredients for each variety of glass, which produces a material possessing the requisite qualities. The results of analyses of the glasses already referred to have been represented by formulæ resembling that of felspar (K_2O, Al_2O_3, $6SiO_2$), felspar being a natural glass. The accepted formula of flint or lead glass is K_2O, PbO, $6SiO_2$: of Bohemian combustion tube, K_2O, CaO, $6SiO_2$, and of plate or sheet glass Na_2O, CaO, $6SiO_2$. As the proportions indicated by each formula are adhered to, so the quality of the glass is insured, provided the raw materials are sufficiently pure. The quality of a glass is the resultant of the qualities of its constituent silicates. It has already been shown that silicates are

compounds formed by the direct or indirect combination of silica with metallic oxides, and that their constitution is exceedingly varied. Silicates are more or less durable according to the greater or less proportion of silica which they contain. The silicates of lead are decomposed by acids, and the sodic and potassic silicates dissolve in boiling water. The plumbic sesquisilicate ($2PbO$, $3SiO_2$), a pale yellow transparent substance, and the potassic or sodic tetrasilicate (Na_2O, (or K_2O) $4SiO_2$), which have been commonly known as glasses, are so unstable as to be useless for those purposes for which true glass is especially valuable. The latter, which has received the name of soluble glass, is obtained by fusing 8 parts of sodic or 10 parts of potassic carbonate with 15 parts of sand and 1 part of charcoal. The charcoal, by robbing the carbonate of oxygen, facilitates its decomposition. The fused mass is dark in colour, but transparent. The different silicates vary greatly in fusibility. The aluminic disilicate (Al_2O_3, $2SiO_2$) and the calcic and magnesic silicates can only be fused with the greatest difficulty. The ferrous and manganous sesquisilicates ($2FeO$, (or $2MnO$) $3SiO_2$) fuse readily, and crystallize on cooling, and the plumbic sesquisilicate fuses with even greater facility. A valuable quality belonging to mixtures of silicates is the fact that the fusing point of a mixture is considerably lower than the mean of the fusing points of the silicates constituting the mixture. Thus, although the aluminic, calcic, and magnesic silicates are practically, when separate, infusible, a mixture of two of the same silicates fuses at a comparatively low temperature. It is also found that a glass containing three or more silicates is more fusible, but less perfect in structure and in purity, than a glass containing two silicates only. The qualities contributed to the different glasses by their constituent silicates are as follows:—Potassic silicate is free from colour, and contributes brilliancy and fusibility. Sodic silicate produces a sea-green colour, but adds to the

fusibility and brightness of the glass. Plumbic silicate, if in excess, causes a yellow tint in the glass, and diminishes its durability; the excess rendering the glass liable to solution by acids, and to lustre-giving decay by combination with sulphur. Plumbic silicate increases both the fusibility and ductility of glass, and by raising its density adds greatly to its refractive power, and consequently to its brilliancy. The density of the silicate, however, is a constant source of trouble. Flint glass is a mixture of the plumbic and potassic silicates, of two materials differing vastly in specific gravity. If oil and water be stirred together a veiny and streaky effect is produced; the veins and cords which so commonly disfigure ordinary flint glass, and which can only be obviated in the optical flint glass by great and prolonged labour, are, in like manner, due to the inequality in density of the two constituent silicates. Baric silicate, without imparting any colour to the glass, increases the resultant density and brilliancy, though in a less degree than the plumbic silicate. Calcic silicate, when the calcic oxide is in excess, produces a milky appearance, but otherwise is chiefly valuable as supplying stability. The calcic and sodic silicates in comparison with other constituent silicates are the least removed from each other in specific gravity, and consequently yield a glass of great homogeneity.

Bottle glass, a mixture of the silicates of sodium, aluminium, and calcium, and Venetian glass, a mixture of the silicates of sodium, potassium, and calcium, are readily fusible, but are deficient in purity and lustre; the latter defect, however, and the small specific gravity of Venetian glass, are reckoned as advantages.

CHAPTER III.

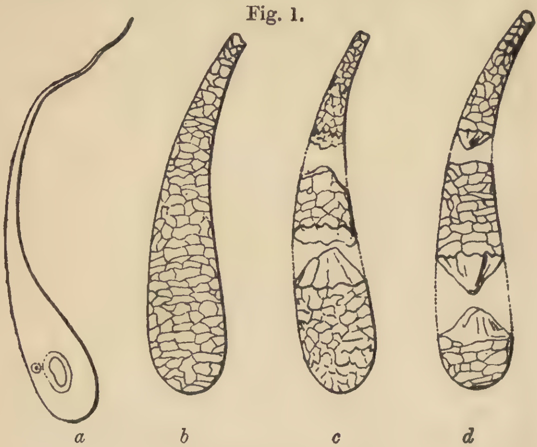
The Chemical and Physical Qualities of Glass. (Continued.)

THE most important property belonging to mixtures of silicates, but one which is not equally developed in all mixtures, is that curious condition of viscosity, intermediate between solidity and liquidity, which is induced and is maintained by heat, and which renders possible the chief processes of the manufacture of glass. After the decomposition of the raw materials of glass in the crucible, after the expulsion of the gases, and the combination of the silica with the metallic oxides, the glass which is formed passes by imperceptible stages into a liquid condition. This condition the glass maintains as long as it is subject to the full heat of the furnace in which the crucible rests, but if the heat be slightly diminished, or the glass chilled by exposure to the air, the property of ductility, viscosity, or tenacity is acquired. In the liquid state glass can be poured or ladled directly from the crucible ; in the viscous state, it can be "gathered" or coiled on the heated end of an iron rod, very much in the same way in which thick treacle can be coiled round the bowl of a spoon. In this condition, if the gathering-rod be hollow, the solid mass collected at the end of the rod can be expanded by the skilful use of the workman's breath into a bulb, which is the germinal or primitive stage of all manufactured glass except that which derives its form from manual or mechanical pressure. The form of the bulb may be modified by causing it to expand and assume the shape of a resisting environment, or may be either flattened or elongated by the force of gravitation. If to a part of the bulb remote from the gathering-iron a second iron be attached by a seal of glass, the bulb may be prolonged into tube. If a solid mass of glass be treated in the same manner it may be drawn out to an almost indefinite length, and to a state of extreme tenuity. If the bulb be severed from the gather-

ing-iron by the unequal contraction of a part of the glass caused by the application of a cold substance, and a solid iron rod be attached to a point remote from the fracture, and the bulb be reheated, and if after reheating, the rod to which the severed bulb is attached be rapidly "trundled," the glass, like the head of a trundled mop, will expand into a disc by the action of centrifugal force, but will be prevented from fracture by cohesion. When a heated vessel of unequal thickness is left by the workman to cool in the open air, the thin parts become cool sooner than the parts which are comparatively thick, and the outer layers of the thick parts sooner than those nearer the centre. By unequal cooling, tension is excited between the thick and the thin parts of the vessel, as well as between the external and internal layers of its substance. A heated vessel which is very thin and of equal substance, may be left to cool with impunity, as the cooling is equal throughout. Sudden cooling applied to one point of a vessel, as by the application of a moistened tool, or by the fall of a drop of water, causes fracture at that point by exciting tension. So also the impact of hot iron upon cold glass, or the introduction of boiling water into cold glass vessels is a common cause of breakage. When molten glass is ladled into water, it becomes brittle and crackled throughout its substance. When a small quantity of glass is gathered from the crucible on an iron rod, and a drop is allowed to fall from the iron into boiling water, and is removed from the water as speedily as possible, it is found to possess curious properties. The shape of the drop, as shown at *a*, fig. 1, is that of a tear with a long tail. The head of the tear is exceedingly hard, and resists a heavy blow without fracture; it also can scarcely be marked by file or diamond. If, however, the tail be fractured by a sudden blow, by pliers, or by the corrosion of hydric fluoride, the entire mass will be disintegrated, as shown in fig. 1, *b*, *c*, *d*, and may be crumbled in the hand without injury. If a tear, made in the same way, be buried in sand and reheated to the point of ductility, and then

allowed to cool exceedingly gradually with the sand in a closed oven, it may be easily marked or scratched, and may be broken with the same facility and the same fracture as ordinary glass. A shaped vessel dropped from the workman's rod into boiling water, whilst still red hot and retaining part of its ductility, is immediately broken up, but the liability to fracture is reduced by substituting for the water liquids which can be raised to higher temperatures than the boiling point of water. This principle is the founda-

Fig. 1.



Prince Rupert's Drops.

tion of M. de la Bastie's invention of hardened or "toughened" glass. The use of boiling fat in the place of water for immersing the heated glass renders possible the hardening of vessels of simple form. Several difficulties attend the process, which at present have been only partially overcome. It is essential that the whole surface, and as far as possible the whole substance of a vessel, should be simultaneously affected by the change of temperature produced by immersion in the liquid. It will readily be

understood that if one part is chilled sooner than another the whole vessel will suffer. In order that simultaneous cooling may be attained, every part of a vessel must be at the same temperature, a condition which is almost impossible to be fulfilled if the vessel consists of several parts; the substance of the vessel must be equal throughout, and the whole surface of the vessel must at the same time come in contact with the liquid. The last condition implies that the air contained by a hollow vessel can be expelled through a strongly resisting liquid in an inappreciable space of time. The nature of glass which has been immersed in the molten fat, closely resembles that of the tears of glass dropped into boiling water. The hardness of the surface of vessels treated by this process, like that of the tears, is sufficient to withstand considerable violence, and the fracture of both is identical; moreover, a microscopic examination of a fragment of the thicker parts of a hardened vessel discovers the substance to be divided by a porous and striated band, which is in marked contrast to the solidity of the superior and inferior crust.

The disadvantage of the practical use of the hardening process, in addition to the difficulties which have been already referred to, is the unreliability of the glass produced. Reliable strength and durability can at present only be obtained in glass by allowing it, after manipulation, to cool as gradually and as regularly as possible. Gradual cooling, or "annealing," is practically attained by exposing the red-hot glass to a source of considerable heat, and either gradually withdrawing the glass from the heat, or allowing the source of heat gradually to become extinct. The best explanation of the various phenomena connected with the rapid and gradual cooling of glass is afforded by the hypothesis of the repulsive force excited between the molecules of matter by heat. Under the influence of this force bodies tend to expand, and finally to change their condition of aggregation. This hypothesis assumes the existence of physical pores, which increase in

size as the body passes from the solid to the liquid and from the liquid to the gaseous condition. If therefore the liquidity of glass be caused by the increase in the size of its inter-molecular pores, the stages of viscosity, ductility, and solidity will result from the gradual diminution of the same. When glass is allowed to cool gradually, its pores will become regularly closed or diminished in size throughout the entire substance, and it will acquire regular and reliable strength ; whereas when glass is rapidly cooled the crust will be intensely solidified, whilst the molecules of the interior will be withheld, by adhesion to the crust, from uniting and reducing the internal porosity. Glass is a bad conductor of heat, and this property tends to aggravate the difference in condition between the crust and the interior of the material when rapidly cooled. It is only the intense solidity or hardness of the crust of rapidly cooled glass which withholds the mass from collapse, and as soon as the solidity is weakened, disintegration necessarily ensues.

CHAPTER IV.

The Chemical and Physical Qualities of Glass. (Continued.)

ORDINARY glass apparently lacks crystalline structure ; when, however, it is subjected for a long time to a temperature just insufficient to cause fusion, it is converted into a porcelain-like crystalline substance. The change is supposed to be effected by the partial separation of certain silicates, especially those of calcium and aluminium, and their adoption of a crystalline form : a mass of these crystals analyzed by Dumas gave the formula $18(CaNa)O, 2Al_2O_3, 45SiO_2$. All glass is subject to this change, which is known as "devitrification," but glasses of complex constitution are more liable to it than the simpler varieties. Devitrification is artificially induced by heating glass embedded in gypsum or sand ; it sometimes occurs

accidentally, when a crucible still containing molten glass is allowed gradually to become cool by the extinction of the fire to which it had previously been exposed. The curious material known as Reaumur's porcelain is glass which has been artificially devitrified. Devitrified glass may be restored to a vitreous condition by fusion. When exposed to a moist atmosphere it is liable to decay by the exudation of a soluble salt. The opacity or partial opacity of inferior window-glass after prolonged exposure to weather is due partly to decay and partly to devitrification, a film of insoluble crystalline calcic silicate causing the actual obstruction of light. The subject of decay and corrosion of glass has been fully and ably treated by Mr. J. Fowler, F.S.A., in "Archæologia," vol. xlvi., but rather from an archæological than a technical standpoint. All glass yields readily to the corrosive action of hydric fluoride, silicic tetrafluoride being formed ($4HF+SiO_2 = 2H_2O+SiF_4$). Sulphuric, nitric, hydrochloric, and phosphoric acids will also, under favourable circumstances, tend to decompose certain varieties of glass. Decay in glass may also be readily produced by alkaline solutions, and even to a certain extent by the prolonged action of boiling water. The experimental exposure of glass to superheated steam under great pressure results in the decomposition of the glass together with the formation of a substance akin to "augite," and containing minute crystals of pure quartz.

The signs of decay, whether produced artificially or naturally, are, in the first place, a slight coloured tinge or iridescence; secondly, gradually increasing opacity, and finally, decomposition. The causes of natural decay, which take effect only after the lapse of many years, are the atmosphere or the earth and their contents. The corrosive elements in both cases being moisture, in conjunction with carbonic acid and ammonia. Glass, however, generally possesses internal foes more powerful even than those attacking from the outside, and it may be safely asserted

that glass freed from its internal enemies is practically indestructible by natural causes. Considerable light has been thrown upon the subject of the decay of glass by the noticeable decay of the glass pigments applied to church windows erected in recent years, the pigments consisting of finely-ground glass mixed with a metallic oxide as a source of colour and fused to the surface of the glass by exposure to a moderate heat. There were found to be two causes of decay present in the pigments applied to the glass—firstly, the infusible metallic oxide mixed with and not chemically combined with the glass, and secondly, a proportion of borax added to the powdered glass with a view to effect the fusion of the pigment to the glass background more evenly and at a lower temperature than could be effected with the powdered glass alone. The infusible metallic oxide did not itself adhere to the glass, and by preventing the glass in contact with it cohering, rendered the paint porous and liable to inroads from without. The borax, even after fusion, being hygroscopic, absorbed moisture from the air and gradually exuded, leaving weak points for the incursion of moisture, and rendering the final disappearance of the pigment inevitable.

Applying this knowledge to the decay of the actual substance of glass, it is found that the durability of glass is directly increased or diminished as its composition approaches or recedes from that required to form a definite chemical compound. An excess of silica, of one of the metallic ingredients, or of a foreign material, as for instance chromic oxide, which has escaped solution, weakens the cohesion of the mass and consequently the durability of the glass. An excess of an alkaline ingredient necessitates the formation of a soluble silicate, which must gradually be dissolved, and leave a pitted surface adapted for the collection of additional moisture and for the consequent increase of the work of destruction. In glass which has been buried for a great number of years there is a marked deficiency of alkaline material.

CHAPTER V.

Glass and Light.

THE well-known effects due respectively to the reflection, refraction, or transmission of beams of light by glass may be considerably modified by variations in the nature of the glass employed. The accuracy of the reflection of glass mirrors is due to the smoothness or evenness of surface produced naturally or by mechanical polishing. The surface of glass which has been rendered imperceptibly uneven by incrustation or decay gives rise to the effect of iridescence which has recently been artificially imitated with considerable success. Reflection from numberless dispersed infusible particles contained in the substance of glass gives to it the effect of possessing a pale blue colour. Substances which will produce this effect are the oxides of tin, arsenic, and aluminium, as also metallic gold and copper when reduced from their salts by chemical action.

The refractive power of a glass is proportionate to its molecular weight, and is artificially increased by the admixture or substitution of ingredients which will add to the density of the resultant material: amongst the ingredients employed for this purpose are plumbic and zincic oxides and the carbonates of barium and thallium. The colours of the spectrum are produced by the dispersive and refractive power of the prism through which the beam of light has passed. Glass which has acquired the property of double refraction by reason of an unequal modification of its elasticity induced by curvature pressure or sudden cooling, when traversed by a beam of polarized light, produces curious geometrical effects of colour and darkness, which vary according as the glass has a rectangular, circular, or triangular form, and according to the degree of tension of its particles. Fluorescence, or the visibility of the ordinarily invisible ultra violet rays of

the spectrum, is observable with glass, the ingredients of which have been fused with a small proportion of uranic sesquioxide. When light passes through a transparent body, the body appears colourless if all the vibrations are transmitted in the same proportion in which they exist in white light. If some of the vibrations are checked or extinguished, the emergent light and consequently the transparent body possesses the colour produced by the combination of the unchecked vibrations.

The oxides of certain metals, when introduced into the crucible with the ingredients of glass, become dissolved in the resultant glass, and possess the power of retarding or extinguishing certain of the vibrations of white light. The oxides of iridium, gold, cobalt, and in some cases copper, have so great a power of extinguishing light vibrations, as to produce the effect of black opacity, even when mixed with the glass in comparatively small proportions. Opacity is, however, generally obtained by an infusible and insoluble excess present in the substance of the glass: as, for instance, black opacity by the oxides of manganese and iron, and the white opacity and opalescence of enamels, by the oxides of arsenic, tin, and calcium, by calcic phosphate, fluor-spar (CaF_2), and cryolite ($6NaF, Al_2F_6$). The power of extinction and retardation possessed by a dissolved metallic oxide is modified according to the nature of the metal, its condition of oxidation, and the quantity of the oxide present. That the oxides of different metals, as well as the different oxides of the same metal, yield different effects of colour, is readily proved by experiments with borax beads holding metallic oxides in solution and exposed to the influence of the blow-pipe flame. In the oxidizing flame, iron gives a deep orange colour, manganese a violet, nickel a reddish brown, copper a peacock blue or green according to the quantity present, cobalt a purple blue, and chromium an emerald green or yellow. In the reducing flame the two latter colours remain unchanged, the orange colour of iron becomes a

dull green, the violet of manganese disappears, the brown of nickel changes into a grey turbidity, and the blue or green of copper is converted into red.

The oxides of iridium, platinum, thallium, cadmium, antimony, yttrium, erbium, and didymium fused with the ingredients of flint glass in experimental proportions give respectively the following results. The oxide of iridium gives a dense black glass; the oxide of platinum, a glass which is grey and turbid; the oxide of thallium, a greenish-yellow glass; the oxide of cadmium a pale yellow glass; the oxide of antimony, a yellow glass, and the oxides of yttrium, erbium, and didymium, give colourless glasses. Upon the foregoing and similar experiments have been based the principles of practical glass colour-making. Certain metallic oxides produce the same effects of colour with all varieties of glass and in whatever manner they are treated: others, to produce particular tints, or, in some cases, any colour at all, require special manipulation. The oxide of cobalt, if not in excess, always gives a characteristic purple blue; the uranic sesquioxide gives a bright fluorescent yellow; the oxide of lead in excess gives a pale yellow, and the oxide of chromium gives an emerald yellow passing into green. If the latter oxide be in excess, the excess remains in the form of sparkling crystals embedded in the glass. The oxides most commonly employed by the manufacturer, except the oxide of cobalt, and which require special manipulation, are the oxides of silver, gold, manganese, iron, and copper. The oxide of silver, when mixed and fused with the ingredients of glass in the ordinary manner, is invariably reduced, and the metal is found at the bottom of the crucible. The oxide is therefore mixed with a convenient medium, applied to the surface of finished glass as a pigment, and exposed to a moderate heat in a kiln or oven. In this manner the surface of the glass becomes tinted by an absolutely permanent yellow stain.

Gold is used to produce a pink ruby glass, and for this

purpose is dissolved in a mixture of nitric and hydrochloric acids, and the solution is added to the ingredients of flint-glass. There are, however, two dangers to be avoided—firstly, the super-oxidation of the gold, resulting in the production of auric oxide, which does not colour glass; and, secondly, the conversion of the oxide into metallic gold by reduction, which gives to the glass the curious property of transmitting a blue colour whilst reflecting a dull reddish brown. The ruby colour is probably due to aurous oxide; ingredients must, therefore, be mixed with the glass to regulate and limit the oxidation of the metal. The glass when gathered from the crucible is absolutely colourless, and before acquiring colour must be chilled and reheated. The colour when gained is so intense that gold ruby glass can only be used as a casing to a colourless base. As shown with the borax bead, manganic oxide yields a violet colour, but glass containing manganous oxide is colourless. Manganic oxide, however, when exposed to prolonged and intense heat, parts with a proportion of its oxygen and is thereby converted into the manganous oxide. In preparing violets, pinks, and reds from manganic oxide, care must be taken to regulate the heat so that the colour be not lost. The evolution of oxygen from large quantities of this oxide gives rise to porosity and ebullition throughout the fused glass with which it has been mixed.

A large proportion of ferric sesqui-oxide gives a yellow colour to glass, whereas ferrous oxide, even in small quantity, produces a perceptible dull-green tint. Ferric oxide when exposed to heat has a tendency to part with oxygen and become ferrous oxide. Metallic iron, mixed with the ingredients of glass, combines with oxygen to form the ferrous or the magnetic oxide. The ingredients of glass generally contain metallic iron or ferric oxide as an impurity. Even the purest samples of sand contain traces of iron. The dark-green of bottle-glass, and the dull tint of inferior table and window-glass are alike due to the presence

of ferrous or magnetic oxide. If the proportion of ferrous oxide be very trifling its colouring power may be destroyed by adding with the ingredients of the glass a small quantity of pure manganic oxide, which yields oxygen and converts the ferrous into ferric oxide. For the same purpose, and especially in the manufacture of plate and sheet-glass, the arsenious anhydride is employed. This substance, when exposed in small quantities to intense heat, is decomposed, owing to the vaporization of the metal, the oxygen remaining available for cleansing the glass. The reason of the preference for the arsenious anhydride to the manganic oxide in the preparation of glass for windows is that if the slightest excess of the manganic oxide has been used, the glass, after long exposure to weather, acquires a pink tinge, although, when first glazed, it may have been apparently colourless. In preparing a yellow glass with ferric oxide, it is necessary to add manganic oxide, in order to maintain the oxidation of the iron. Similarly in preparing reds and pinks with manganic oxide, a proportion of ferric oxide is added to prevent the reduction of the colouring agent. The oxides of copper are distinguished as cupric and cuprous. Cupric oxide in small quantities gives a peacock-blue glass, which is converted into a green, if the proportion of the oxide be considerably increased. From the cuprous oxide the rich blood-coloured ruby of Bohemian glass is obtained. The cuprous oxide passes readily into the cupric condition by the assimilation of oxygen. For this reason, in the preparation of copper ruby glass, not only must all oxidizing agents be avoided, but powerful reducing agents must be added. If the reduction be carried beyond a certain point, the spangled effect of avanturine, due to reflection from particles of reduced metal, is produced.

Copper-ruby glass, like that prepared from gold, is colourless when gathered from the crucible; and if, after it has gained its ruby colour, it be exposed too long to a high temperature, the ruby disappears, and is replaced

by a dull brown. The ruby colour, when perfect, is exceedingly powerful. The modification of the colour-transmitting power of glass, by a change in the oxidation of the metal which it contains, has been illustrated by the different colours belonging to the different oxides of copper and iron. The modification effected by concentrating the solution of an oxide has been illustrated by the change of copper-blue into green; and a similar change may be observed from blue to red by accumulating slips of glass tinted to a deep blue with oxide of cobalt. The purity and true nature of transmitted effects of colour can only be determined by spectroscopic examination. The general result of the observation of a beam of sunlight which has passed through coloured glass is the shortening of the visible spectrum, together with the intensification of some bands of colour, and the entire or partial obliteration of others. Certain glasses, and especially those containing the oxides of erbium and didymium, show the vertical absorption bands characteristic of the respective metals. The purest colours, according to the spectroscope, are the copper-green and blue, the iron-yellow, and the copper-red.

CHAPTER VI.

Raw Materials.

SAND is the commercial representative of silica. The quality of glass is mainly determined by the quality of the sand used in its composition. The impurities generally present in sand are iron, lime, alumina, chalk, and magnesia. The quality of a sample of sand is estimated according to the quantity of iron contained by it. For common bottle-glass, sand is obtained in sufficient purity from the sea or river shores; for better qualities of glass, the

sand is quarried as sandstone, and ground to powder. The purest sands at present in use in this country are obtained from quarries in the Forest of Fontainebleau, in France, and from Alum Bay, in the Isle of Wight; specimens, however, of great purity have been sent from America. Sand of inferior quality is obtained in considerable quantities from Wales, Bedfordshire, and Lancashire. An analysis of a sample of the Fontainebleau sand gives as result: silica, 98·8; magnesic oxide, aluminic oxide and iron, 0·7; moisture, 0·5. The best test for sand is examination with the microscope. Practically, pure sand should be perfectly white, and should not effervesce or change colour when heated with hydric chloride. Metallic iron, or the oxide of iron, being soluble in the acid, can be detected in solution by testing it with potassic ferrocyanide. Effervescence with a dilute acid indicates the presence of a carbonate, probably chalk. Pure sand is insoluble in all acids, except hydric fluoride. For the manufacture of the finest glasses, the sand is subjected to the preliminary processes of washing, burning, and sifting. In the first, the sand, after being agitated with a large volume of water, is allowed to settle by gravitation, whilst the lighter particles of dirt, chalk, and other extraneous matter are removed in suspension, by withdrawing the water from above.

The object of "burning" is to remove moisture and organic matter. The sand is placed on the bed of an oven, and is played upon directly by the flame in its passage from a fireplace on one side to flues rising immediately opposite. In the centre of the bed of the oven is a trap-door, by the removal of which the sand, after sufficient exposure to the flame, can be lowered into a vault beneath. The sieves through which the sand is passed before being mixed with the other ingredients, are covered with fine copper gauze.

Red lead (minium, Pb_3O_4, density about 9·08) is a compound of the protoxide with the dioxide of lead ($2PbO, PbO_2$). It possesses a brilliant red colour, is insoluble in

acids, but is decomposed by many of them, and especially by hydric nitrate, a salt of the protoxide being formed, and the brown dioxide being left. Red lead, when exposed to a high temperature, is decomposed, oxygen being evolved, and the protoxide remaining. It is for this reason preferable to litharge for the manufacture of glass, the evolved oxygen serving to combine with any organic matter that may be present, and to convert ferrous into ferric oxide. The purity of red lead may be tested by the microscope and by heat; a sample strongly heated in a covered crucible should leave a residue of a yellow colour. Red lead is obtained by heating metallic lead, so as first to obtain the protoxide. The oxide thus obtained is ground with water, dried, and exposed on the bed of a reverberatory furnace to a heat of about 300° C. During this process, the protoxide is constantly agitated with a long iron rake, in order to expose every particle to additional oxidation. In the preparation of the protoxide any foreign metals more oxidizable than the lead are removed with the first portion of the oxide; whilst the copper and silver, being less oxidizable, accumulate in the portions of the oxide which are produced last. The intermediate portion is, therefore, preferable for the manufacture of glass.

Calcic carbonate, chalk ($CaCO_3$). Density, 2·72. Chalk, the form in which calcic carbonate is generally used, often contains traces of clay, made up of silica, alumina, and oxide of iron. A pure sample of chalk should entirely dissolve in dilute hydric chloride.

Baric carbonate ($BaCO_3$). Density, 4·3. Baric carbonate is prepared from baric sulphate, which is reduced to the form of sulphide by ignition with carbonaceous matter; the sulphide is then dissolved in water, and decomposed by a current of carbonic anhydride, which precipitates the baric carbonate as a white powder.

Sodic Chloride, Sulphate and Carbonate ($NaCl.Na_2SO_4$ Na_2CO_3). The sulphate and carbonate being derived from the sodic chloride, attempts have been made to

utilize the latter directly for glass-making. It has, however, at present only been used for the commonest quality of coloured glass. Sodic sulphate is made from common salt (sodic chloride) and oil of vitriol (hydric sulphate) in vast quantities, under the name of salt cake, as a preliminary process in the manufacture of the soda ash or sodic carbonate. The second process is the making of black ash, or impure sodic carbonate mixed with sodic sulphide, by the deoxidation of the salt cake in the presence of chalk by means of heat and carbon. ($Na_2SO_4 + 4C + CaCO_3 = CaS + 4CO + Na_2CO_3$.) The third process consists in separating the sodic carbonate by means of solution and evaporation.

Potassic Carbonate (K_2CO_3).—The sources of potassic carbonate are wood-ashes, the residues of the manufacture of beet sugar and alcohol, and the carnallite ($MgCl_2$, KCl) of the Stassfurt mines. In the latter case the potassic sulphate is first formed and the carbonate is manufactured by the reduction of the sulphate by a similar process to that employed in making sodic carbonate. The following is the result of analysis of an average sample of a carbonate formed from the chloride :—

Potassic Carbonate.	Sodic Carbonate.	Potassic Chloride.	Potassic Sulphate.	Water.	Residue.
79·17	3·55	0·59	0·17	15·95	0·47

Cryolite (6NaF, Al_2F_6) is found naturally in large quantities in Greenland.

Manganic Dioxide (MnO_2), occurs naturally as pyrolusite. As the natural ores generally contain traces of iron and cobalt, it is best to use for cleansing glass the oxide precipitated by chemical means.

Zaffre, which is largely used for colouring glass blue, is a very impure oxide of cobalt obtained by imperfectly roasting cobalt ore, mingled with two or three times its weight of sand. The other oxides employed for colouring glass are used in a practically pure condition.

Fire-clay plays such an important part in the manufacture of glass as to deserve special notice. In England it is principally quarried from beneath the coal in the Staffordshire coal-measures, the Stourbridge fire-clay being noted for its excellence. The fire-clays of Glen-boig, near Glasgow ; of Forges-les-Eaux, in France ; of Namur, in Belgium ; Sargenau in Switzerland, and Schwarzenfell in Bavaria are also famous. After being raised from the mine the clay is exposed in heaps for a considerable period to the disintegrating action of the weather, it is then ground and sifted according to the purposes to which it is to be applied. The theoretical composition of pure fire-clay is represented by the formula Al_2O_3, $2SiO_2$, $2H_2O$. The following table of analyses shows the variation in the composition of clays taken from different positions in the same deposit:—

Water and organic matter .	5·11	6·70	6·0	8·33
Silica	79·25	72·04	70·10	64·82
Alumina	13·57	18·79	20·39	23·87
Ferric oxide	1·38	1·68	1·60	1·74
Calcic ,, ...	0·08	0·69	1·35	0·33
Magnesic oxide	0·42			
Alkali, loss, &c.	0·19	·10	·90	0·91

In selecting clays for fire-work by the results of analysis, it must be remembered that the infusibility of a clay increases with an increased proportion of silica and alumina, and diminishes with the increase of the proportion of the other ingredients. If the proportion of the latter rises above a certain point, fire-clay can be fused into a glass by the heat of an ordinary furnace. The colour of fire-clay is often deceptive, as its whiteness may be due to an increased proportion of the calcic or magnesic oxides. The colour of the ferric oxide is often concealed in the unburnt clay by the presence of organic matter, but is revealed by the action of heat. In addition

to infusibility, stability and plasticity are important qualities. The latter is undoubtedly augmented by the process of weathering, although the actual effects of the weather are not clearly understood. Organic matter and sulphides are probably oxidized, and the particles of the clay are broken up by moisture and frost. The quality of stability or non-contractibility under fire is increased by the increase of the proportion of the silica at the expense of the alumina, and by the decrease of the proportion of the fusible constituents. The best practical test of a sample of fire-clay is to form the sample into a brick, to break the brick into two pieces, and to expose one piece to any required heat whilst retaining the other for comparison. If the clay is of good quality the colour of the burnt piece will be white, and the two fractured ends of the burnt and unburnt pieces will fit exactly. Fire-clay is used for building crucibles, for forming the shaped blocks and bricks of which furnaces are constructed, and as a substitute for mortar in all building connected with fire-work.

CHAPTER VII.

Crucibles.

GLASS crucibles, in addition to the actual weight of the molten glass, are exposed to two dangers —namely, intense and prolonged heat from without, and the corrosion of the raw materials from within. The effect of corrosion is readily proved by heating for a long time in a small crucible such substances as borax, red-lead, or potassic or sodic carbonate. After a crucible has been in constant use for several months, and especially if it has contained flint or lead glass, the back and bottom will be found to be covered with innumerable small dents, which have undoubtedly been formed by corrosion.

The complaint, so commonly heard, of specky glass, arises from the presence in the glass of white particles of an infusible aluminate formed by the combination of the alkaline or metallic ingredients of the glass with the alumina of the crucible. If the corrosion becomes concentrated at one point and prolonged for a considerable period a breach is formed, through which the molten glass escapes into the furnace. Knowing the dangers that have to be encountered, manufacturers are extremely careful in the selection and preparation of the clay as well as in the construction of the crucibles. The finely sifted raw clay, on its arrival at the glass manufactory, is mixed by sifting with a proportion, varying from one-ninth to one-fifth of its weight, of burnt-clay of considerably coarser grain. The coarser particles tend to bind the clay, and render the finished crucible less liable to crack from variation of temperature. The burnt clay is derived from the unglazed fragments of broken crucibles. The burnt and unburnt clays are placed in a shallow lead-lined bin, measuring some ten feet square, and water is gradually added, until the mixture possesses the consistency of a stiff paste. The clay-paste may be kneaded in a "pug-mill" by the artificial mastication produced by the onward pressure of helicoidally arranged knives in a confined cylindrical space, but is more usually subjected to the primitive process of "treading." "Treading" consists in pressing and kneading the clay-paste little by little with bare feet. It is commonly supposed that the warmth, elasticity, and sensibility of the naked foot develops the plasticity of the clay in a manner which cannot be equalled by mechanical means. The clay is thrice subjected to the process of treading before it is considered fit to be worked up into crucibles. The forms of crucibles are varied according to the nature of the work they are intended to perform. The larger crucibles, which are used for melting plate, sheet, and flint glasses, are entirely hand-made. Plate and sheet glass crucibles

have the form of an open bowl, whereas flint glass crucibles are domed over in order to protect the plumbic silicate of the glass from the reductive action of flame and smoke. The first stages in the manufacture of all large crucibles or glass "pots" are identical. A slab of stone, larger than the base of the crucible, and resting upon a wooden table furnished with wheels, is spread with a thin layer of sand. The foundation of the crucible is laid upon the sand with tapering rolls of plastic clay, which are carefully pressed together until a complete stratum has been formed. The potter scratches ridges across the

Fig. 2.

Plate or Sheet Glass Crucible.

Flint Glass Crucible, Front and Side Views.

surface of the first stratum to form a bond for the second, and repeats the process until sufficient strata have been accumulated to form the bottom of the crucible. The bottom is then consolidated by beating with a mallet, and smoothed and levelled with a wooden straight-edge. Ridges are scratched round the edge of the surface of the bottom in order to form a bond for the wall, and the wall is slowly and laboriously built up roll by roll and layer by layer. As each roll is successively applied it is pressed in such a manner as to drive out the air as far as possible from the substance of the wall. The building of one crucible is not carried on continuously;

several are kept in hand at the same time, and the potter passes from one to the other, so that one may partially set whilst another is being manipulated. The wall of an open crucible is built up straight, or inclining slightly outwards: the wall of a flint glass crucible is built straight up for about twenty-four inches, and then by gradually contracting the diameter of the layers a closed dome is formed, and the crucible assumes the shape of a large beehive. When the crucible has acquired sufficient consistency, an opening in the shape of a half-circle is cut in one side of the dome, the base of the half-circle coinciding with the line at which the contraction of the wall was commenced. This opening is intended for the introduction into the crucible of the raw materials, and for the removal of the molten glass. Flint glass crucibles, although considerably smaller than those used for plate and sheet glass, require a longer time for their completion, owing to the care required in constructing their domes. Crucibles are dried in the same room in which they have been built, as they are too fragile to be shifted with impunity. The room is maintained at a fixed temperature of about 15° C., by means of gas or hot water, and every precaution is taken to exclude frost, draught, or excessive heat. When the crucibles are firmly set, the stones upon which they have been built are removed, and they are allowed to rest upon the wooden carriages beneath. Crucibles should be allowed to mature for at least twelve months before undergoing the baking process preliminary to introduction to the furnace. The baking oven is an arch closed at one end, and temporarily closed at the other with iron doors. A fire-place is placed on one side, and flues which can be opened or closed at pleasure are constructed at intervals in the opposite wall in order to draw the flame in any required direction and convey it to the main shaft. The crucible or crucibles are placed within the arch, being each supported upon burnt fire-clay blocks. The heat is raised with the

utmost caution until such time as the heat of the arch has equalled the heat of the furnace: a result which may be attained in from four to seven days. The removal of an injured crucible from the bed of the furnace to make way for its successor, the preparation of the bed, and the introduction of the new crucible are operations requiring considerable courage, skill, and physical endurance. This will readily be understood when it is stated that in order to facilitate the removal of the broken crucible the furnace is driven to its utmost heat, that during the removal of the old and the introduction of the new crucible the workmen are exposed to the direct heat of the furnace without protection, that the crucibles, both new and old, are at a white heat, and that the tools with which the work is accomplished are, generally speaking, of the most primitive description. The iron carriage upon which crucibles are moved is in the shape of a three-pronged fork, the wheels being attached at the junction of the handle and the prongs. It also has an upright iron bar standing at right angles to the upper surface of the fork and immediately above the axletree, which serves as a fulcrum for working the levers, by which the crucibles are forced into position. The temporary brickwork in front of the broken crucible is first assaulted with iron crowbars, and when a breach has been made the semi-vitrified material which has accumulated around it has gradually to be chipped away by the same means. The broken crucible is then drawn forward, forced upon the iron carriage, and removed. The doors of the arch are thrown open, the prongs of the carriage thrust under the new crucible, and the crucible drawn out of the arch and conveyed to the furnace. The crucible is then levered into position, adjusted with wedges, and a temporary screen is built up partly with fire-clay slabs made for the purpose, and partly with fragments of the broken crucible together with bricks and fire-clay. Before the crucible is fit to receive the raw materials it requires to

be glazed internally with molten glass. The object of this preliminary glazing, as well as of the custom of introducing a charge of broken glass before charging the raw material, is to reduce the amount of damage caused by chemical corrosion. For the same reason the potter carefully rounds the angle between the wall and base of the crucible, in order that there may be no weak places to facilitate the attack. Corrosion is the legitimate end of a crucible, but many fail through neglect. A difference in temperature between the furnace and the arch, or a chill during the transit of the crucible, are fruitful sources of injury. A sudden failure or sudden increase of the heat of the furnace is also likely to cause breakage. Breakage is detected by the subsidence of the molten glass in the crucible, and by the appearance of glass mixed with the cinder issuing from the furnace. If access can be gained to the crack, and air admitted, the flow of glass may be checked by allowing it to solidify by cooling. If this cannot be accomplished the glass must be ladled from the crucible with iron ladles into iron caldrons.

As has been stated, fire-clay slabs are used to form temporary screens in front of crucibles. The mouth or opening of a flint-glass crucible is always provided with a movable door or stopper of fire-clay, which is used to confine the heat during the process of melting the glass. The aperture is also generally partially closed during working hours with a fire-clay collar having very much the shape of a large horse-shoe. In sheet-glass manufactories and in some flint-glass works, fire-clay rings, complete in one piece or composed of two half-circles, are allowed to float on the surface of the molten glass in order to attract impurities, and secure a central space of clear glass from which to gather for working.

CHAPTER VIII.

Furnaces.

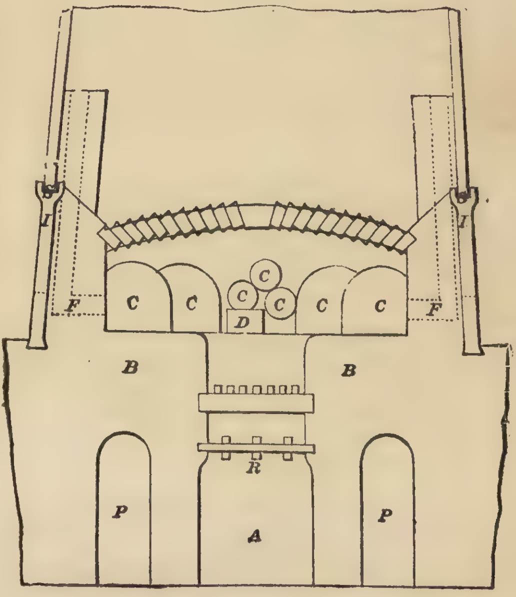
THERE are few processes connected with the manufacture of glass which are not, directly or indirectly, dependent upon heat: by heat, the raw materials are converted into glass; by heat, the glass is manipulated; and by heat, the manufactured glass is solidified. In addition to these more important processes, are the minor operations connected with the preparation of certain of the raw materials, the baking of the crucibles, and with several forms of decoration. The essential qualities of the furnace for the fusion of the raw materials, are, durability, regularity, intensity of heat, and economy of fuel. The necessity for the durability of the furnace may readily be understood when it is stated that the heat of the furnace is continuously maintained for several years. Durability is dependent on the stability of the materials used in construction, as well as upon the construction itself. Furnaces are mainly built of blocks of fire-clay which have received definite forms whilst in a plastic condition. These blocks before being used are allowed to become completely dry, but are not burnt. In building, each block is rubbed against its immediate neighbour until an impervious joint has been formed. The yielding nature of the dry clay facilitates this operation, and so complete is the cohesion between two blocks treated in this manner that they can only be separated with considerable difficulty. Arches may be built without centres, and the domes or crowns of the furnaces may be constructed in concentric rings, beginning from the outside. In furnaces in which open crucibles are used, great care must be exercised in selecting the materials of which the crown-blocks are composed. If a material be used which crumbles when exposed to an

intense heat, the glass in the crucibles is liable to be injured. The crown and the bed, *i.e.* the part upon which crucibles rest, are the most liable to corrosion. For this reason the crown should be well arched, and its surface should be kept free from accumulation of dirt. In some manufactories it is customary to repair defects in the bed, whenever a crucible is introduced, by the insertion of masses of moist fire-clay. Whenever a bed ceases to afford a safe resting-place, the furnace should be condemned and a new furnace prepared with all speed. Upon the regularity of the heat of the furnace depends the safety of the crucibles, as well as the quality of the glass contained. Sudden variations of temperature tend to cause the fracture of the crucibles, and the slightest variation, by disturbing the homogeneity of the molten glass, produces a striated effect. It is needless to remark that pure glass cannot be produced if the heat be insufficient. Economy of fuel is principally dependent upon the construction of the furnace, and various modifications of construction have been introduced with this object. Novelties of construction are, however, regarded by manufacturers with little favour, as however great may be the promised saving, they are aware that intensity of heat, durability, and regularity are the important factors in real economy.

The simplest form of a glass furnace is shown in fig. 3, which is a vertical section through the centre. The passage A runs under the grate of the furnace, and is connected at both ends, either directly or by cross passages, with the outer air. This passage introduces the air necessary for the consumption of the fuel. From this passage the stoker is able to stir the fire from beneath, and into the passage fall the cinders and slag, and the lost glass from broken crucibles: P is a small passage, opening at each end of the grate into the main passage, and enabling the stoker to pass from one end of the grate to the other without going immediately under the furnace: R is an iron rest to support the bars used for stirring the

fire: D is a small iron door for charging the grate with fuel, which is thrown in with a shovel, or forced in by a long rake. The crucibles C rest upon the bed B. The clinker, when coke is used, is thrown into the furnace by the stoker in the form of lumps of broken gas-retorts; but when coal

Fig. 3.

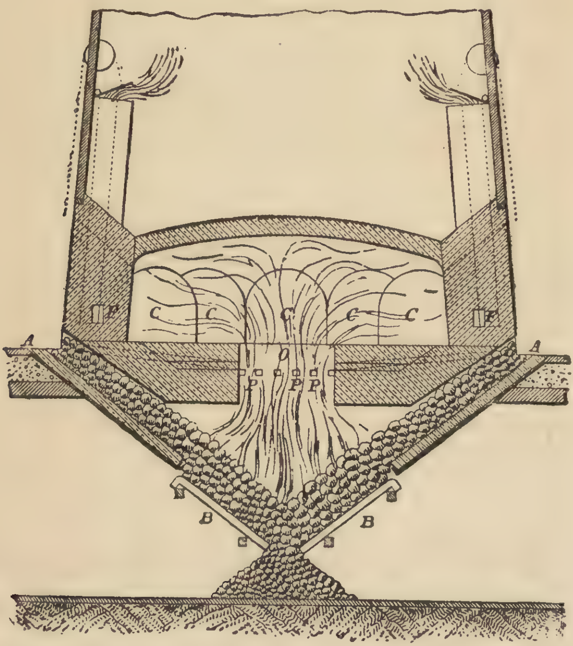


Vertical Section of an Old-fashioned Flint-glass Furnace.

is burnt, it is formed by the coagulation of spent coal. The clinker plays an important part, both in regulating the draught, and in protecting the iron bars of the grate from the heat of the fire. It is one of the stoker's most urgent duties to attend to the condition of the clinker. There must be enough, and not too much; and what there is

must be continually moved in order to prevent the bottom of the furnace becoming impervious to air. Iron staves, I, at each side of every opening of the furnace, carry a continuous iron ring, S, upon which the cone of the

Fig. 4.



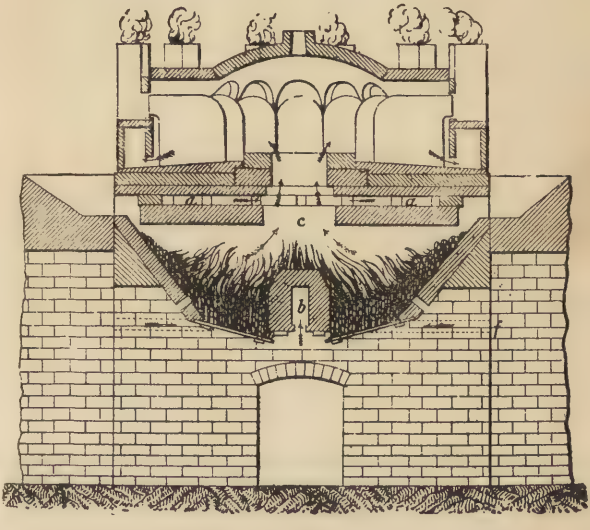
Ingram's Furnace, intermediate between an old-fashioned and a Gas Furnace.

furnace is supported. Flues, F, stand on each side the charging-door and of all the large crucibles. These flues can be cleaned through small doors opening outwards. They are arranged so as to draw the heat, after it has struck the crown of the furnace, all round the lower part

of the crucibles. The dome or crown is kept as flat as possible, in order to economize heat.

Fig. 4 is a vertical section of a furnace, the arrangement of which is intermediate between those of an old-fashioned furnace and a gas-furnace. The fuel is introduced at the ports A, and makes its own way down to the grate-bars, B. By the fuel passing through and under the

Fig. 5.



Boetius' Furnace.

base, crucible space is gained. The partial combustion of the fuel upon the grate-bars generates a gas, which burns with intense heat when brought into contact with the air introduced by the passages, P, cut through the base. By reason of the combustion of the fuel taking place beneath the base, it is possible to reduce the size of the eye, O, of the furnace, and, in this manner, to increase the width of

the base, and consequently the duration of the furnace. The heat is directed by the flues, F, in such a manner as to surround the crucibles, C, as in the furnace just described.

Fig. 5 represents an arrangement known as Boetius' furnace. It was the forerunner of the last, and is very similar to it. The chief difference is, that air is introduced through a perforated column, *b*, as well as through the air-passages, *a*, in the base. The gas and air unite and burn at *c*. The disadvantage of the central column is that any glass which may escape from a broken crucible is retained by the column, and can be removed only with great difficulty.

Frisbie's Feeder.

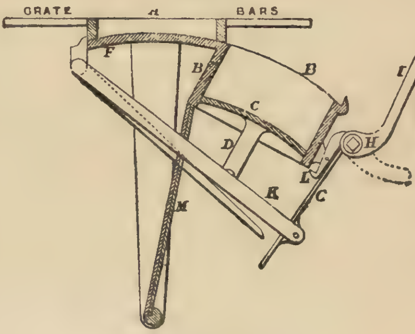
Frisbie's patent feeder provides a method of stoking from beneath the fire, and effects a considerable saving in the consumption of fuel. It consists of a hopper, which is charged below the furnace, and is raised into the centre of the grate by means of a lever. The bottom of the hopper can be forced upwards, so as to introduce the fuel into the furnace, and when the hopper is removed an apron attached to the hopper fills the opening caused by its removal. By this principle of feeding from below the fire, the igniting of the fresh coal is a gradual process, and all volatilized coal, combustible gas, and carbonaceous matter pass from below through the live coals above, and break at once into flame; thus perfect combustion and great intensity of heat are secured. The heat of the surface of the fire is not abated, nor is cold air admitted into the furnace while supplying fresh fuel, so that a perfectly uniform heat is maintained, and, as the hottest part of the fire is constantly at the top, all the heat is utilized, and the grate-bars are preserved from burning and from clinker. The coal is pushed up and outwards equally from the centre of the grate, and the whole fire is stirred and broken up at each fresh supply of fuel, so that no raking is required,

and the coal is evenly consumed, leaving little refuse, except fine ashes which drop down through the grate-bars without raking.

Siemens's Regenerative Gas Furnace.

The gas producers are entirely separate from the furnace where the heat is required, and may be made sufficient in number and capacity to supply several furnaces. The fuel is supplied at intervals of two to four hours

Fig. 6.



Frisbie's Feeder.

A, opening through grate; B, hopper; C, movable bottom; D, plunger to bottom; F, apron; G, rocking bar, attached to H and K; H, rocking shaft; I, hand lever; K, lever carrying hopper backwards and forwards; L, catch; M, arm supporting hopper and apron.

to each producer, through a charging-box, and descends gradually on an inclined plane, which is set at an inclination to suit the fuel used. The upper portion of the incline is made solid, being formed of iron plates covered with fire-bricks; but the lower portion is an open grate formed of flat horizontal steps. Each producer is capable of converting daily about two tons of fuel into combus-

tible gas, which passes off through an "uptake" leading to the furnace. The action of the gas-producer is as follows :—

The fuel, as it descends, becomes heated, and parts with its volatile constituents, namely, the hydrocarbon gases, water, ammonia, and some carbonic acid. There now remains 60 to 70 per cent. of purely carbonaceous matter to be disposed of, which is accomplished by the action of a current of air slowly entering through the grate, producing regular combustion immediately upon the grate. The carbonic acid thereby produced, in passing slowly through a layer of incandescent fuel, takes up another equivalent of carbon, and becomes carbonic oxide, which passes off with the other combustible gases to the furnace. Water may be brought to the foot of the grate, which, absorbing the spare heat of the fire, is converted into steam, which, in its passage through the incandescent fuel, may be decomposed into its elements, after having performed the useful office of disintegrating the clinkers.

The total production of combustible gases varies with the admission of air; and since the admission of air depends upon the withdrawal of the gases, the production of gases depends upon the demand for them. A damper can be inserted in the "uptake," so as to shut off any gas-producer at pleasure.

Fig. 7 is a diagram of a regenerative gas-furnace. Underneath the heating chamber, K, are placed four regenerative chambers, L, which are filled with fire-bricks, built up with spaces between them. The regenerative chambers work in pairs, the two under the left hand end of the furnace communicating with that end of the heating chamber, while the other two communicate with the opposite end. The gas enters the heating chamber through the passage, M, and the air enters through the passage, N, whereby they are kept separate up to the moment of entering the heating chamber, but are then able immediately to mingle intimately, producing at once an intense and uniform

flame. From the air-flue, the entering air is directed by the reversing-valve, P, into the air regenerator, and there becomes heated ready for entering the furnace; at the same time, the gas entering from the gas-flue is directed by the reversing valve, R, into the gas regenerator, where

Fig. 7.

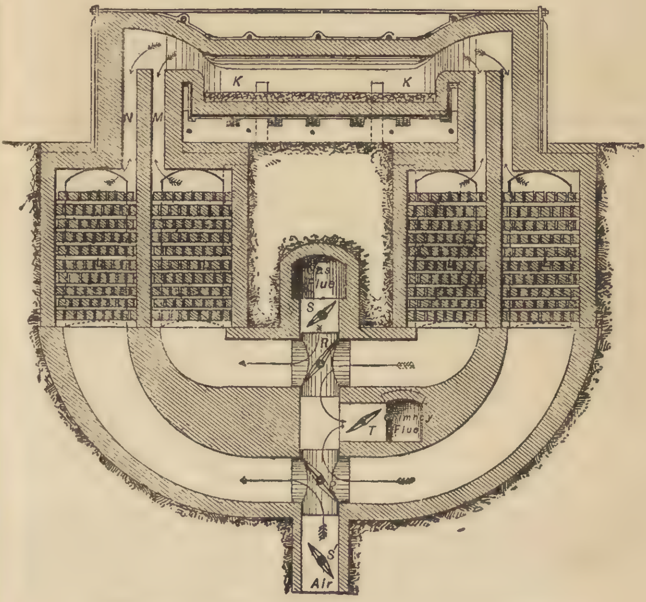


Diagram of a Siemens Regenerative Gas Furnace.

it also becomes heated to the same temperature as the air. The products of combustion, on leaving the opposite end of the furnace, pass down through the second pair of regenerators (as shown by the arrows), and, after being there deprived of their heat, are directed by the reversing valves, P, R, into the chimney-flue. When the

second pair of regenerators have become heated by the passage of the heated products of combustion, and the first pair cooled by the entering of gas and air, the valves, P, R, are reversed by hand levers, causing the currents to pass through the regenerators in the contrary direction, whereby the hot pair of regenerators are now made use of for heating the gas and air entering the furnaces, while the cool pair abstract the heat from the products of combustion escaping from the furnace. The supply of gas and air to the furnace is regulated by the stop-valves, S S, whereby the nature of the flame in the furnace may be varied at pleasure, whilst a chimney damper, T, is used to regulate the amount of pressure in the furnace in relation to the atmosphere, so as to allow the opening of the doors or working-holes of the furnace. The advantages of the regenerative gas furnaces are—(1) saving of fuel, both in quantity and quality; (2) great cleanliness in the manufactory; (3) complete command of the heat.

CHAPTER IX.

Annealing Ovens.

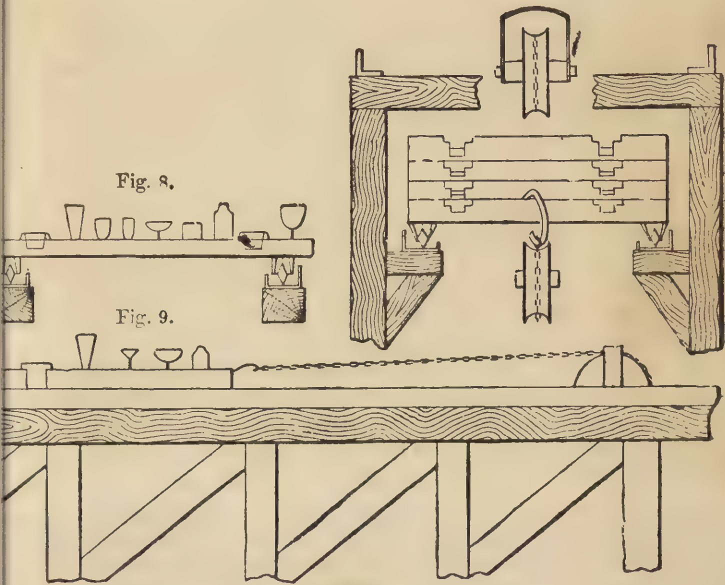
THE simplest and oldest arrangement for annealing is a tunnel, about thirty feet in length, either provided with a lateral fire at one end, or heated (as at Murano works) by the waste heat from the melting-furnace, and having a tramway, with movable trucks for the goods, running down the centre. The trucks are mounted on small solid iron wheels, protected from the fire by the projection of the body or pan of the truck, and are moved by an endless chain and a windlass; the pans are provided with hooks, so that they can be fastened together, to form a continuous train. Figs. 8 and 9 are different views of such

an arrangement. Fig. 10 is a section showing a tramway, beneath the main tramway, on which the pans or trucks, after they have been emptied at the end of the tunnel farthest from the fire and the glass-house, are returned to the glass-house by means of an endless chain. The pans

Fig. 10.

Fig. 8.

Fig. 9.



Old-fashioned Annealing Oven.

are piled one upon another, and the lowest is hooked into the endless chain by which they are drawn from one end of the tunnel to the other.

Another arrangement for accomplishing the same purpose, is a flat, horizontally-revolving iron wheel, worked upon the same principle as a turntable. The diameter of

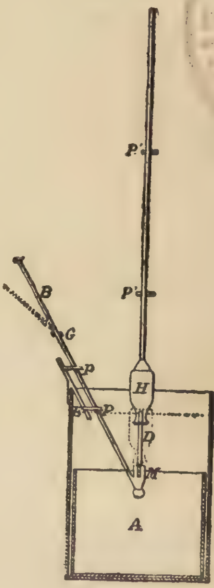
this wheel is from 25 to 30 feet. The goods are placed upon the wheel at one point near a fixed source of heat, and by the wheel are carried away from the heat to another point, where they are removed and sorted. This is a very perfect arrangement, and works continuously. Its disadvantage is the large amount of space in the centre of the wheel, which is practically useless.

Yet another arrangement for annealing glass has been devised by Dr. C. W. Siemens. In this the glass to be annealed is placed on a travelling furnace-bed mounted on wheels and heated in a permanent furnace. When this truck has been filled, it is wheeled out of the furnace, and over it is immediately placed a cover, the edges of which are so immersed in sand as to prevent all access of air. The truck is then wheeled away and allowed to cool, whilst another is put in its place in the furnace.

The heat of the main furnace is most commonly used to assist manipulation. Convenient openings are placed in the walls of the furnace, or in case of flint-glass, the mouths of the crucibles are pressed into the service. In some cases, however, it is found more economical to erect small separate auxiliary furnaces for manipulative purposes, than to use the main furnaces. Where auxiliary furnaces are employed the whole heat of the main furnace can be devoted to fusing successive charges of raw materials, and a continuous supply of molten glass can be secured. This arrangement is less essential in flint glass manufactories than in other glass works, as the nature of the work produced in the former requires greater time and consequently the strain upon the glass is less severe. The flues of auxiliary furnaces are generally carried into the stack of the main furnace. In some old-fashioned flint-glass works, a wide-mouthed crucible, in which the heat is augmented by burning beechwood logs, is set apart for the manipulation of all large vessels of superior quality. Reference has already been made to the furnaces employed for preparing the sand and red lead, and for baking the crucibles.

M. de la Bastie's discovery of a process for hardening glass by immersing it whilst still in a semi-ductile condition, in a heated liquid, was commonly supposed to offer a substitute for "annealing." The process has not succeeded for reasons which have already been stated, but it will be convenient at this point to describe the arrangements and apparatus by which it is conducted. The temperature of the liquid must be adjusted to the chemical nature of the glasses used. The temperature for a soft glass is 68°—75° C. (154°—167° F.). The liquid preferred is molten mutton-fat. The simplest form of the process is that used in the treatment of open-shaped vessels, such as tumblers and finger-basins. These are treated in the course of manipulation, being dropped into a bath of molten fat instead of being sent to the annealing oven. For this purpose a bath of fat, heated to the necessary temperature by a small gas-stove, and containing a lining of wire-net, is placed as near to the workman as possible. The heat of the bath, once acquired, is maintained by the heat of the vessels immersed in it. When the wire-net is full, it is removed with the glasses and another substituted. The glasses when taken from the net are arranged on sieves in an iron closet, which can be heated. The temperature of this closet is raised to about 70° (158° F.), causing the fat, which still adheres to the glass, to drip through the sieves into a tank beneath, where it is collected for future use. From the heated closet the

Fig. 11.

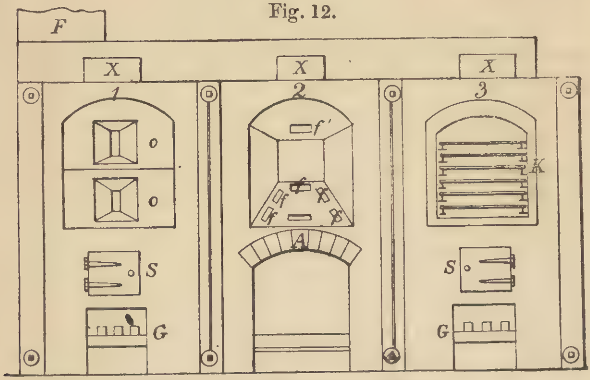


M. de la Bastie's Process.

glasses are removed to a tank containing a solution of sodic hydrate, which is also slightly heated, and thence to a bath of warm water.

The most serious obstacle to the application of the discovery to vessels of general utility is the difficulty of expelling the air contained in bottles and other utensils with narrow apertures sufficiently quickly to allow the interior and exterior surfaces of the glass to be simultaneously affected by the liquid. The apparatus which has

Fig. 12.



Old-fashioned "Burning-in" Kilns.

been devised to overcome this difficulty in the case of both large and small vessels is represented in fig. 11. In fig. 11 A represents the bath, B a bent tube, supported on guides at P, and having a pocket, M, to receive any of the liquid which may enter the end of the shorter arm; E is the surface of the liquid. The bottle, H, is depressed to D, by the rod adhering to its base, and guided by supports, P′P′. The air escapes by B, and the liquid takes the place of the air. The rod is detached, and B, D, is canted over so as to allow the bottle to slip off and into the net.

Pieper's Process.—Pieper's process for hardening glass

differs from that of De la Bastie, although the results are similar. Glass vessels are heated almost to the point of plasticity, and are then subjected to the action of injected superheated steam.

The kilns used for burning-in stain and enamel for decoration are represented in fig. 12; 1, 2, 3 may be regarded as the same kiln in different conditions; S, is the firing-door; G, the grate; O, cast-iron screens placed one upon another, with protruding openings to allow the stoker to watch the progress of the glass within; K, cast-iron casing or muffle, with iron shelves resting upon ridges projecting from the sides of the muffle, upon which the pieces of glass rest; the inside of the muffle is always carefully coated with whiting, and the shelves are covered with a layer of plaster of Paris, in which the glass is imbedded; *f*, openings, allowing the fire to pass from the grate, and through the arch A, in such a manner as to surround the muffle, and to pass off through *f′* into the main flue, F; X, soot-doors.

Thompson's patent gas-kiln, the exterior of which is shown in fig. 13, is in every respect greatly to be preferred to the old-fashioned kiln already described. The fuel employed is the ordinary lighting gas mixed with atmospheric air. Not only is the actual cost of burning, kiln for kiln, reduced, but the saving of time is so considerable that a gas-kiln can efficiently burn in two hours the same class of work as by the old method would remain ten hours in the kiln. The pressure of the gas from the main is regulated by the handle A. The gas passes to the right and left through the pipe B B, and enters the kiln through a series of jets; fourteen jets connecting the supply with the kiln on each side. The construction of the jets is shown in fig. 14. Each jet has a separate tap, so that the supply of gas to any part of the kiln can be accurately regulated, and the heat of any part can be increased or diminished at pleasure. Atmospheric air enters at the holes, a a, and becomes mixed with the gas before

entering the kiln. A current of air is created by the flue G, connected with the chimney D, and is controlled by the dampers E E. The kiln is constructed with fire-bricks, and is bound together with angle-irons and tie-bolts; F F are cast-iron doors opening outwards, and furnished with spy-holes, S S, through which the progress of the burning can be observed. W is a cast-iron carriage running on a tramway, T T, in such a manner that it can readily be introduced or removed from the kiln whenever the doors are open. The base of the carriage X acts as

Fig. 13.

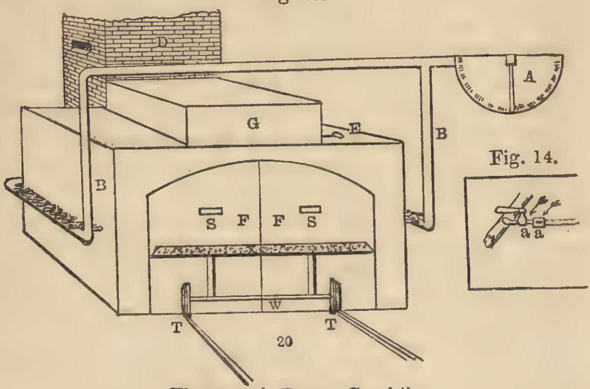


Fig. 14.

Thompson's Patent Gas-kiln.

the bed of the kiln. A duplicate carriage is desirable, so that one can be loaded with glass whilst the second is in the kiln. The base X entirely fills the kiln, and is lined with plaster, so as to protect the iron-work of the carriage from the heat, and to form a heat-retaining bed for the glass. By a recent improvement, the base can be canted so as to facilitate the simultaneous burning of large vessels as well as of flat glass, and also for bending glass. The practical working of the kiln proves its economy, regularity and cleanliness.

CHAPTER X.

The Manipulation of Glass.

Blown Hollow Ware.

THE processes connected with the manipulation of molten glass can be better classified by reference to the character of the products than to the chemical nature of the material. No classification of glass ware can be absolutely complete, but a satisfactory result may be obtained by dividing manufactured glass into hollow and flat ware, and by sub-dividing these two classes in accordance with the distinctions observed in the trade. The result of this classification is as follows :—

- Manufactured glass.
  - Hollow ware.
    - Blown glass.
      - Bottle glass.
      - Blown glass, tube, and lamp work.
    - Pressed glass.
  - Flat ware.
    - Sheet and crown glass. Mosaic glass for windows.
    - Plate glass. Optical glass.

Hollow ware.

Hollow ware is placed first, not on account of its intrinsic importance, but because the bulb hollowed by the workman's breath is the germ of the great majority of wares both flat and hollow. It moreover includes the increasingly important products of the manufactories of pressed glass.

The sub-division, blown glass, includes the manufacture of all vessels, domestic, scientific, or decorative, which directly or indirectly owe their ultimate forms to the

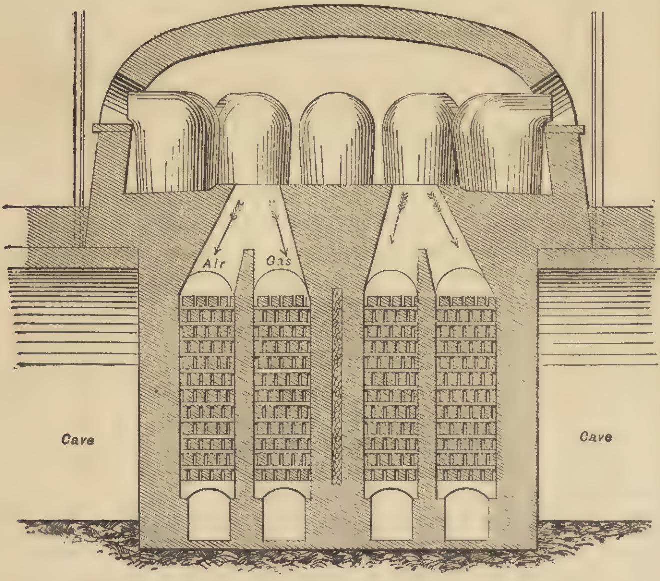
glass-blower's breath. Every variety of true glass, when in a molten condition, can be blown with greater or less facility; the subject is therefore not limited by the chemical nature of the glass employed, but embraces the blown wares of Great Britain as well as those of Belgium, France, Venice, and Bohemia. In describing the processes of manipulation, it will be convenient to depict the arrangement and processes of our own manufactories of flint and bottle-glass, and to notice, where necessary, the differences observable abroad. When comparing the products of the manufactories of different countries with regard to brilliancy, colour, lightness, purity, and subtilty of workmanship the nature of the material must be taken into consideration. Venetian and Bohemian glass is necessarily light, and should be homogeneous, owing to the approximation of the densities of the constituents; its freedom from lead also assists manipulation by allowing the use of the direct heat of the furnace. The glasses of Great Britain, France, and Belgium, being commonly lead glasses, are heavy, and are liable to striation, arising from the unequal densities of the silicates of which they are composed. A lead-glass cannot be exposed to the reductive action of flame, and retains plasticity for a comparatively short time. On the other hand the silicate of lead contributes brilliancy in a marked degree, and assists in the development of every shade of colour excepting the ruby tint characteristic of cuprous oxide. The expression "flint glass" by which English blown ware is commonly known, is misleading, and might well be replaced by a title of greater accuracy. A glass consisting of a mixture of the silicates of lead and potassium would more appropriately be characterized as a lead or potassic-lead glass. The accepted formula of the ordinary English lead-glass (PbO, K_2O, $6SiO_2$) can be approximately realized by mixing together three parts by weight of pure sand, two parts by weight of minium or red-lead, and one part by weight of the hydrated potassic carbonate. With

these chief ingredients are mixed small proportions of potassic nitrate and arsenic sesqui-oxide, together with sufficient manganic-oxide to neutralize the effect of any metallic iron or ferrous oxide that may be present as an impurity. The transparency, colourlessness, and homogenity of the resultant glass depend upon the proportion and purity of the materials, as well as upon the intensity and regularity of the heat to which they are exposed. The materials are thoroughly mixed together by means of fine copper or brass-wire sieves, and added to proportions of broken lead-glass, or of lead-glass, which, having been previously melted, has been ladled from the crucibles for the purpose. The mixture is now ready to be introduced into the crucibles. The form of a lead-glass crucible is shown at fig. 2; the height averages forty inches, the outside diameter thirty-six inches, and the inside depth from *a* to *b*, which is the depth of the glass, averages twenty-three inches. The crucible is domed over, and the opening is so placed as to be beyond the probable range of the fire, in order that the glass may be protected from reduction. The crucibles stand with their backs to the source of heat, and with their mouths projecting through apertures suitably arranged in the external wall of the furnace. A crucible holds from ten to twelve cwts. of glass, and is commonly filled by four successive charges, one being allowed to become partly melted before the next is added. Between each charge the mouth of the crucible is closed by means of a fire-clay slab and moist fire-clay, a small aperture only being left for the escape of gas. The old-fashioned circular coal or coke furnaces with certain economical modifications, which have been noticed in Chapter VIII., are still most commonly used. An adaptation of Siemens's regenerative system to a lead-glass furnace is shown in fig. 15.

The mouth of the crucible, as has already been stated, is commonly used, both for the withdrawal of glass, and as a source of heat for the workman's use. The workman is

partially protected by a door of iron-work and fire-bricks, which is hinged upon one of the uprights supporting the cone. The bottom of the door is rather below the level of the lip of the crucible, the body of the crucible being screened by a projecting temporary structure of bricks,

Fig. 15.



Dr. Siemens's Regenerative System applied to a Lead-Glass Furnace.

slabs, and fire-clay. Upon this structure is placed an iron grooved support for the blowing or working rods. On one side of the mouth of the crucible, and projecting into the furnace, is a fire-clay box or "shoe," in which the ends of the workman's irons are heated preparatory to "gathering." Above the "shoe" is a small circular opening in

the temporary wall of the furnace, which can be closed at pleasure, and which, when opened, may be used as a supplementary source of heat, as a means of attracting the fire towards the crucible, or as a spy-hole by which to dis-

Fig. 16.

Lead-Glass Workman in his "Chair."

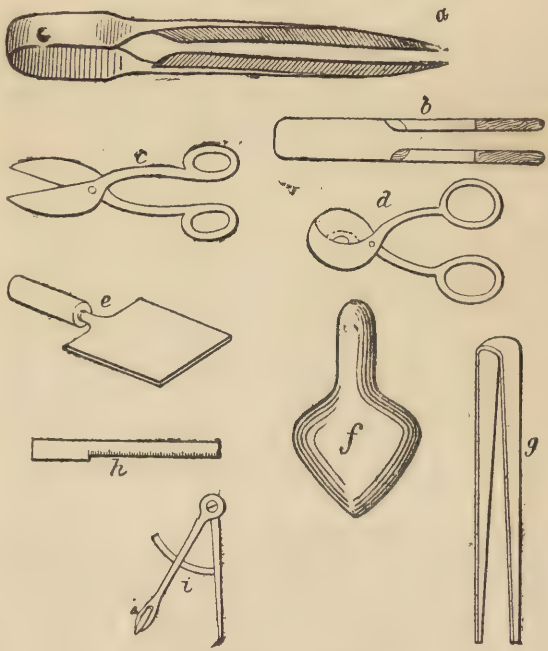
cover the condition of the furnace or of the crucibles on the opposite side.

The blowing-iron or blow-pipe is a long hollow iron rod, varying in length from 5 to 6 feet, and in external dia-

meter from three-quarters of an inch to 2 inches, according to the weight of glass it is intended to gather. The working rod or "puntee" (Fr. point) is, in its simplest form, a light rod of tapering solid iron, varying greatly both in length and strength; it is used for holding a vessel during the later stages of manipulation, by means of a seal of glass. The seat in which the glass-blower works is, in England, his most important tool. By its means the blowpipe or working rod is converted into the spindle of a lathe or throwing-wheel of the utmost delicacy. In Bohemia the workman's knee commonly serves the same purpose. The construction and form of the "chair" will be readily understood by reference to fig. 16, in which a glass-blower is shown at work. The chair consists of a long strongly-built bench, with transverse projecting arms. The arms are perfectly parallel, but slope slightly downwards from back to front. The workman resting his iron upon the arms, and rolling it backwards and forwards, communicates to the vessel fastened to the end of the iron a rotatory motion, the speed of which can be increased or diminished with the greatest nicety. The glass-blower's principal hand-tools are shown in fig. 17: *a*, is the sugar-tong spring tool, or "tool:" the workman grasping the tool in the middle with his right hand, and compressing the blades upon the glass, to which a rotatory motion is given by his left hand by means of the working or blowing-iron, is able to regulate the form of the bulb, or by increasing the pressure, to divide it completely: *b* is a similar tool, with the blades replaced by movable pieces of wood: it is principally used for opening the bowls of tumblers and wine-glasses, which are liable to become scratched or marked by contact with iron: *c* is an ordinary pair of shears for removing a surplus of thin glass, and *d* shears for severing the ends of handles or rods of considerable substance: *e* is a flat square of polished iron with a wooden handle, known as the "battledore," and used for flattening the square bottoms of tumblers, or other similar purposes:

f is a blow-pipe of glass or metal, used for expanding the opened end of a bulb, or for chilling part of a vessel during manipulation, in order that it may retain its form or substance whilst another part is being fashioned: *g* is a pair of ordinary pincers for seizing and shaping the handles of

Fig. 17.



Glass-Blower's Tools.

jugs, or the decorative filagree work on vases: *h* is a measure-stick, and *i* a compass for marking with a fragment of wax the amount of surplus to be removed with the shears from the edge of a wine-glass or tumbler-bowl. A simple spring balance for comparing the weight of a vessel

with that of its pattern, together with an assortment of measures and calipers, and of different sizes and modifications of the implements already mentioned, complete the essential equipment of the glass-blower.

CHAPTER XI.

Manipulation of Blown and Hollow Ware.

THE uses of the tools referred to in the last chapter will be best explained by describing the processes employed in the manufacture of a few of the simplest vessels, namely, a tumbler, a jug, and a wine-glass. A sufficient weight of molten glass is first gathered or coiled upon the heated end of the hollow iron blow-pipe, the right weight being determined by the nicety of the gatherer's touch. The mass of molten glass adhering to the end of the blow-pipe is consolidated by trundling upon a large polished slab of iron resting upon a substantial wooden stool, and known as the "marver" (Fr. marbre). The mass is expanded into a bulb by blowing through the blow-pipe, and the bulb is lengthened by swinging. If the vessel is to be a round-bottomed tumbler, the bulb is expanded and lengthened, until it assumes the proportions indicated by eye, calipers, and measure, and is severed from the blow-pipe by the application of a chilled iron at a point sufficiently distant from the base to allow the rough severed edge to be removed by shearing. To the round end of the severed tumbler a working rod is attached by a seal of molten glass, and the workman handling the rod proceeds to open and finish the mouth. To effect this result the tumbler has several times to be inserted in the mouth of the crucible, in order to regain sufficient plasticity to allow of shearing and manipulation. When the form and edge is perfect, the sheared edge being melted until perfectly smooth, the tumbler is severed from the working rod by

a sharp blow, and is carried off to the annealing oven. If the tumbler be required to be square-bottomed, the end of the bulb is squared by pressure against the "battledore," or by an apparatus to be described later. In forming a jug, the preliminary processes are similar to those already described. A small quantity of glass for the handle is gathered upon the working rod, and rolled upon the marver. The glass is elongated by holding it downwards, and pulling it with a pair of pincers. When the diameter is correct, the free end is made to adhere to the side of the jug, and the opposite end is severed from the working rod by a pair of shears adapted for the purpose. The severed end of the handle is now bent round, and attached to the jug, either above or below the first connection. The curve of the handle is regulated by reheating and fashioning with a piece of rounded wood, and the lip is formed by pressure with the same implement.

In the manufacture of a wine-glass nearly every principle of glass-blowing is illustrated. The glass for the bowl is first gathered, and blown to the required size and shape. Upon the centre of the base of the bowl, which is still attached to the end of the blow-pipe, a small quantity of molten glass is skilfully dropped from the end of a working rod. Part of the added glass is formed into a small button by the grip of the spring tool, and the residue is pulled out into the stem. In the meantime a smaller bulb has been blown, and its extremity fixed to the end of the stem from which the button has previously been removed. The smaller bulb is severed in the midst, and the cup-shaped remnant adhering to the stem is reheated, opened by the insertion of one point of the spring tool, and by rapid rotation thrown out into a disc or foot by the agency of centrifugal force. In the blowing of the bowl of a wine-glass are illustrated the expansion of plastic glass by the breath, the elongation of the bulb by swinging, or the expansion without elongation produced by raising the bulb, and blowing up into it from below. The ductility of glass

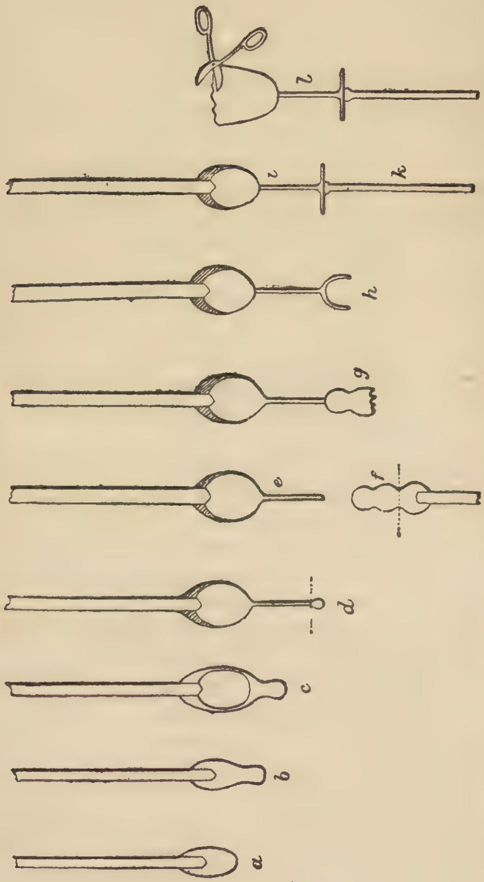
is shown by the manner in which the stem is extracted, and the result of rapid rotation by the sudden expansion of the foot. Moulds are used for several purposes—(1) for giving to glass such forms as cannot be developed by simple blowing; (2) for accelerating the blowing of ordinary vessels; and (3) for impressing on glass superficial decorative patterns. If it be desired to blow a vessel of an oval or rectangular form, or so to blow it that it may exactly fit into some particular space, a mould of the required form is prepared in cast iron or plaster of Paris, care being taken that it shall be pierced with a sufficient number of holes to allow the escape of the air contained between the glass and the mould. A mass of glass is then gathered, marvered, slightly expanded, and thrust into the opening of the mould, the internal shape of which it is compelled to adopt by vigorous blowing.

After the required form has been obtained, the surplus glass connecting the blow-pipe with the vessel may either be blown out thin, so as easily to be broken away, or the blow-pipe is simply severed from the surplus, which is left to be removed by the glass-cutter after it has been annealed. Common vessels of almost every shape may be formed by blowing glass into metallic moulds, which, to allow the delivery of the finished goods, are made in two, three, or more pieces hinged together. (Compare Bottle Glass.) The objection to the use of metallic moulds is the injurious effect which they produce on the surface of the glass. This objection has been overcome by the use of wooden or carbon moulds fitted into metal frames, or for simple forms, as for tumbler and wine-glass bowls, of hollowed blocks of the same substance. These moulds are much more commonly used in France and Bohemia than with us, and a foreign glass may often be detected by feeling the edge of the bowl or lip, which instead of being rounded by melting, is left square by the cutter's wheel. The process employed is to blow the bulb inside the mould, to affix to the moulded bulb the foot, stem, handle, or other

appendage, and to leave the finishing of the part which was attached to the blow-pipe to be accomplished by the glass-cutter after the vessel has been annealed. Superficial patterns are produced by corresponding patterns raised upon or cut into the internal wall of a conical metallic depression. If a solid mass of glass be simply pressed into such a depression and then expanded, the pattern will be entirely superficial; if however, a bulb be blown and expanded so as to fill the mould, the pattern can be felt on the internal as well as the external surface of the glass. The impression of the mould is in either case softened and sometimes almost obliterated by the subsequent expansion of the bulb.

It is necessary now to describe the methods and processes of manufacture in greater detail. Wine-glasses or goblets are classified by the nature of their stems, or by the nature of their feet. A wine-glass may have a "straw stem," or a "stuck shank," and its foot may be either "blown" or "cast." The wine-glass, to which reference has already been made, had a "stuck shank" and a blown foot. By "stuck shank" is meant that the stem is made from a separate piece of glass added to the bowl, whereas a "straw stem" is a stem pulled out of the substance of the bowl itself. Fig. 18, *a* to *l* show the stages of the manufacture of a straw stem wine-glass with a blown foot. *a* is the solid mass of molten glass, *b* is the same marvered and pinched by the tool, *c* is the same expanded into a bulb with the knob pinched by the tool and conveniently shaped for being drawn out as shown at *d*; the small button is removed and the stem is ready to be joined to the bulb *f*, which has also been pinched by the tool as shown: the small bulb attached to the stem is compressed and divided by the tool where it is shown to be indented, and the residue is opened out into the foot. A working rod is attached by a seal of glass to the base of the foot, and the bowl is detached from the blow-pipe by the applica tion of a moistened iron, the workman retaining the

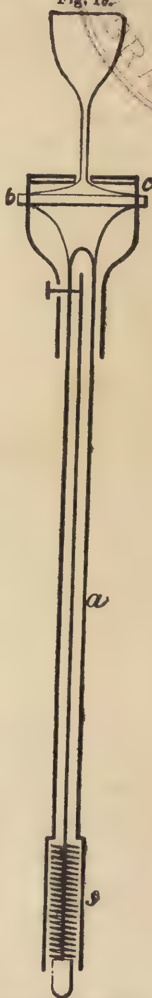
Fig. 18.



Stages in the Manufacture of a "Straw-stem" Wine-glass, with "Blown" Foot.

working-rod in his hand. The workman reheats the severed edge, shears it even, and smooths and rounds it by melting. The wine-glass is then separated from the working-rod by a sharp jerk, and sent to be annealed. The mark of the glass seal by which the working rod was attached to the foot has to be removed by polishing after the glass has been annealed. This process, which is attended with delay and considerable risk, is now avoided by substituting for the working-rod and seal of glass, a rod with a spring holder, which clips and holds the foot, and liberates it when the wine-glass is complete, without injury. The construction of the spring clip will be seen in section at fig. 19. By depressing the outer coating (*a*) upon the spring (*s*) a space is left between the plates *c d* for the admission of the foot, the upper plate being in the shape of a horse-shoe. As soon as pressure is removed, the spring presses the foot which rests upon (*a*) against the stationary horse-shoe, plate *c*. A "cast" foot is one formed from a solid mass of molten glass dropped upon the end of the stem, and flattened by the "battledore." A simple and effective apparatus for making cast feet has recently been introduced, and is shown at fig. 20. 1 and 2 are boards or plates of wood or prepared carbon hinged together at 3, 3, and with a strap (4) to regulate the extent of their opening; 5 is the workman's hand, and 6 a strap for the insertion of his thumb. The workman's right hand compresses the soft glass between the opened boards of the apparatus,

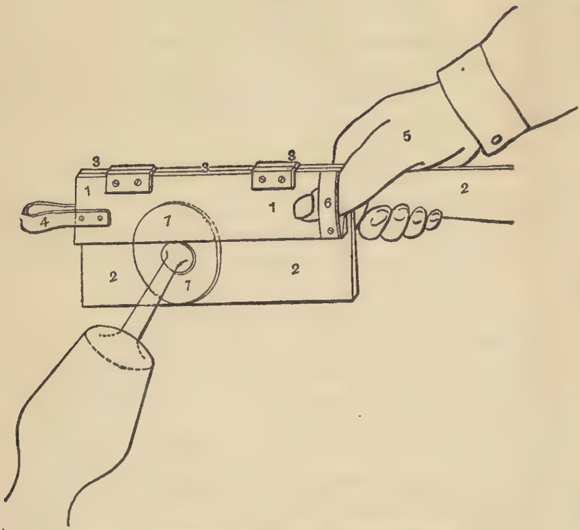
Fig. 19.



Spring Tool for holding Wine-glasses.

whilst his left hand rotates the wine-glass, which is still attached to the blow-pipe. As the pressure is increased the foot is gradually formed, and the burning of the wood or carbon in contact with the hot glass tends both to facilitate the operation and to give a superficial polish to the foot. The continental method of wine-glass making differs in a few

Fig. 20.



Apparatus for making "Cast" Feet.

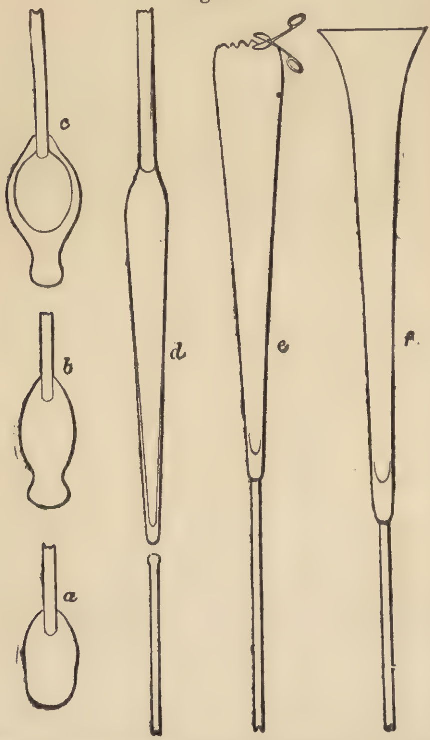
minor points. The workman when shearing the bowl, which he is obliged to do when the bowl is not blown in a mould, is assisted by a boy with a battledore which is so held as to level the edge. Before finishing the wine-glass, an assistant blows into the bowl with a glass blow-pipe, which prevents the necessity of touching the inside of the glass with the tools, and by chilling and hardening the edge secures it

from becoming thick by melting. The English workman attains the same result by trundling the glass during reheating, and by constantly withdrawing it from the source of heat. In dropping on feet or stems the continental workman holds the blowing iron perpendicularly with the bottom of the bowl or the stem uppermost, and an attendant supplies the hot glass from above, sufficient being cut off with shears for the required purpose. This method prevents the occurrence of blisters and marks where the separate pieces are joined. The English workman holds his blow-pipe obliquely, allows sufficient molten glass to fall from the assistant's iron, but uses no shears to detach it. Sufficient has already been said concerning the ordinary manufacture of tumblers. The machine for shaping the bottoms and sides of heavy tumblers consists of a disc of flat iron of the same size as the bottom of the tumblers to be formed, to the circumference of which rods are attached perpendicularly, slightly exceeding in length the height of the tumblers; the disc is fixed to a spindle resting obliquely in a frame and can be rapidly rotated by means of a fly-wheel rigidly connected to the remote end of the spindle. A bulb of glass of the required size is thrust into the midst of the projecting rods and pressed and blown against the disc, which is caused rapidly to rotate. The disc flattens the bottom of the tumblers, whilst the rods shape the outside by friction. The application of handles, which may be either hollow or solid, has already been explained. The process of adding a spout to a vessel is considerably more complicated. The spout must be added whilst the vessel is connected with the blow-pipe, and is consequently air-tight. At the point where the spout is required a mass of molten glass is allowed to fall, which melts the part of the vessel in immediate contact with it. The workman immediately blows through the blow-pipe, and the pressure of his breath forms a breach at the point which has been weakened by additional heat and forces the molten drop of glass outwards in the form of a closed tube.

The workman seizes the tube with his tools and gives to it whatever form may be required.

A similar, but opposite process, is employed when it

Fig. 21.



Stages in the Manufacture of the Trumpet of a Long Vase.

is desired to form a separate compartment in a vessel, connected with the outer air, but separated from the contents of the vessel. In this case the workman, instead of blowing through the blow-pipe and forcing the molten

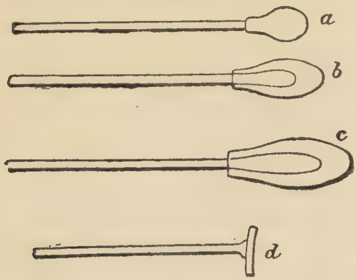
glass outwards, sucks at the blow-pipe and by suction and the pressure of the external air forms a closed bulb in the interior of the vessel. Fig. 21, illustrates the formation of long trumpets or vases which are attached by metal fittings to glass stands, and which have, in some cases, exceeded ten feet in length: *a* is a mass of solid glass, *b* the same indented with the tools, and *c* the same hollowed by the breath; the bulb *d* is elongated by swinging, a working-rod is attached to the extremity, and the end of the bulb is severed from the blow-pipe. The workman holding the working-rod reheats and shears the severed end, and by heating and trundling throws out the rim into the form of a trumpet-mouth (*ef*). If whilst the rim is still plastic, and immediately after it has been thrown, the vase be held perpendicularly with the mouth downwards, the rim will assume by gravitation a crumpled form of exquisite beauty. In fig. 22 a workman is shown holding a vase in the position requisite for producing this effect. The manufacture of glass tube and rod or cane depends upon the almost unlimited ductility of molten glass. In making solid glass-rod or cane a mass of glass is gathered and consolidated by rolling upon the "marver." The mass is lengthened by swinging, and to the end remote from the blow-pipe a thick disc of glass adhering to a working-iron is attached. The workman, retaining the blow-

Fig. 22.

"Throwing."

pipe, and an assistant the working-rod, they gradually recede from each other, walking backwards. The greater the distance by which the two men are separated the greater will be the length and the smaller the diameter of the cane. Tube is made in the same manner as cane, with the exception that the mass of glass is blown into and hollowed before being extended. Ladders placed on the ground act as a guide to the workmen, and serve as a rest for the cane or tube whilst still hot and liable to injury. Cane of great substance, and tube which is intended to resist high pressure, require to be annealed,

Fig. 23.



First Stages of Tube Drawing.

whereas ordinary cane and tube are not generally so treated. The stages of tube drawing are shown in fig. 23: *a* is the marvered glass, *b c* the same expanded, and *d* the working-rod with the disc of glass attached. The shape given to the mass of glass, whether solid or hollow, as well as the shape given to the hollow itself, will be retained by the cane or tube after extension. By moulding the sides of the mass so as to convert it into a square or triangle, or by flattening the sides so as to form an oval, the resultant cane or tube will respectively retain a square, triangular, or oval form. If a stout bulb be flattened and then dipped into the molten glass so as to

gather around it additional glass, and if the compound mass be marvered and drawn out in the ordinary manner, a circular tube with a flattened bore will be the result. These facts are taken advantage of in preparing tubes for thermometers. A flattened bore makes the mercury more visible, and if the surrounding glass be triangular and the angle be in front of the bore, the bore appears to be magnified. Thermometer tube, backed with enamel, is formed by applying a thin cake of molten white enamel glass upon one side of a flattened bulb, coating the whole with molten glass, marvering and moulding to any required shape, and drawing out in the same manner as ordinary tube.

The tube drawn for thermometers and barometers is cut into convenient lengths, but the final processes of introducing the mercury and sealing the ends of the tubes rest with the optician and lamp-worker. The "lamp" consists generally of an air jet, a gas jet, and a pair of foot-bellows, or of a gas jet, or oil lamp and a mouth blow-pipe. Tube or cane can speedily be rendered ductile by the intense heat of the blow-pipe flame, but care must be taken in manipulating lead-glass or enamel to prevent the glass becoming reduced or "smoked." The German glass is not liable to this defect, but is less easily worked, and more brittle. A variety of goods for scientific, domestic, and medical purposes are produced by the lamp from tube and cane. At the present moment large quantities of tube and a considerable body of lamp-workers are busy making and closing the bulbs employed for the incandescent electric lamps. In Murano vast quantities of coloured cane and tube are transformed into beads by the same means. From cane, or in fact any solid glass rendered ductile by the blow-pipe flame, an infinitely fine thread may be drawn out, which, if attached to the circumference of a rapidly revolving wheel, and if the source of glass and heat be continuous, may be indefinitely extended. In order to render the thread more durable it is annealed by heating the wheel upon which it is being spun. Spun

glass has been used for embroidery, as a substitute both for feathers and silk or satin, and as a filtering medium in the laboratory. The manufacture of variegated cane or tube belongs rather to decorative than to practical glass-making. A mass of molten glass attached to the blow-pipe is pressed into a circular, open mould, around the inside of which short lengths of fine white or coloured enamel cane are arranged in niches cut for the purpose. The mass is withdrawn with the canes adhering to its surface, and after being marvered to effect amalgamation, is drawn out into tube or cane. If short lengths of the variegated cane, produced as described, be substituted for the plain white or coloured canes, the section of the resultant cane will bear some resemblance to a flower. Pretty effects may be obtained by incorporating the sections of the flower-cane in the body or bowl of a wine-glass, goblet, or decanter, and surrounding the artificial blossoms with engraved foliage. The network of enamel threads, with or without bubbles in the interstices, so commonly seen in the bowls of Venetian vases, is formed by an application of the same principle. A bulb of transparent glass is inserted and expanded in the mould containing the enamel canes, and is marvered and incorporated with them. The end of the bulb remote from the blow-pipe is attached to a working-rod, the end severed from the blow-pipe is opened, the bulb is formed into a cup, and the upper half of the bowl of the cup is bent back upon the lower and smaller half, so as to form a smaller cup with double walls. A mass of molten glass, which must be pricked or moulded if bubbles be required, is inserted, the cup is severed from the working-rod to which it was attached, and is incorporated with the mass of glass by marvering. The incorporated mass may now be re-heated and blown into any required form. In casing a mass of colourless glass with a colour, it is customary, when the casing cannot be gathered from a crucible, to re-heat a lump of the coloured glass, and when plastic, to form it

into a cup into which the colourless glass can be inserted, and with which it may be incorporated. Sections of flower-cane or small bas-reliefs moulded in some infusible material, may be introduced into a bulb attached to a blowing-iron and temporarily opened at the opposite extremity for the purpose. If the opening be closed, the bulb re-heated, and the walls of the bulb made to collapse upon the included objects by the exhaustion of the air by suction, the solidified mass may be incorporated in the base of a vase or basin.

CHAPTER XII.

Decorative Processes.

THE processes of applying decoration to the surface of blown hollow ware, may be divided into those applied before and those applied after the glass has been annealed. To the former class belong casing with colours, scales and metals; frosting or crackling; surface moulding; insertion of enamel reticulation; application of threading, gems, seals, frills, flowers, and metallic etchings, and iridizing by deposition: to the latter class belong iridizing by corrosion; cutting and engraving in various branches; engraving and roughing by the sand-blast; etching; painting with enamels; gilding; silvering; carving. In addition to the method of inserting the colourless glass into a cup of a coloured glass, "casing" or "plating" may be effected either by gathering from the crucible a casing of colour upon a colourless nucleus, or more usually by gathering the colourless glass upon a nucleus of colour. For every process of casing the coloured glasses must be especially prepared, so as to agree with the base. If the coloured glass be harder or softer, or even if it be hotter or colder

than the glass upon which it is to be plated, the resultant vessels are almost certain to be fractured. For the imitation of coloured pottery, tortoiseshell, and marble, it is customary to spread upon the marver powdered opaque glass of the required colour, and to roll the molten mass of glass in the powder before it is expanded and manipulated. In the same manner scales of mica, and gold or platinum leaf, may be permanently embedded on the surface of glass. The well-known appearance of "crackled" glass is due to the immersion of the vessel whilst still ductile in cold water, and the subsequent re-heating of the vessel in order to neutralize the naturally injurious effect of the sudden change of temperature. Surface moulding may produce impressions which are only perceptible to the touch on the external surface, or impressions which are perceptible on the internal surface as well. In the former case the solid molten glass is pressed into an open mould, and is subsequently expanded; in the latter the bulb is actually expanded in the interior of the mould. The usual impressions imparted by moulds are ribs or ridges, network, and honeycomb or trellis-work. The insertion of enamel reticulation has already been described. By affixing the extremity of a mass of molten glass, gathered upon a working-rod, to a given point on the surface of a vessel still attached to the blowing-iron, and rapidly trundling the blowing-iron, a thread of glass may be evenly coiled round the vessel. A machine is now in common use to give an even rotatory motion to the working-rod during the process of "threading."

Gems or seals are formed by letting fall upon a vessel in course of manufacture, small drops of white or coloured glass, and immediately pressing them with metallic seals. If instead of a drop a line of molten glass be applied to the side of a vessel and a metallic wheel with an indented edge be run over the line, the pattern on the edge of the wheel will be reproduced continuously on the glass. Upon vessels in course of manipulation, glass seals which have

been previously prepared and gilded, and sections of glass flower-cane may be fixed. If exceedingly thin sheets of glass be coated with gold leaf, and etchings be executed in the leaf, the etching may be incorporated in glass vessels by the cohesion produced by heat through the pores of the leaf. Artificial iridescence is caused by the deposition upon heated glass of metallic tin from the fumes of stannous chloride.

Processes applied to Annealed Glass.

Iridescence by corrosion may be obtained by plunging the vessels in a dilute solution of hydric fluoride, or by heating them with hydric chloride in an hermetically closed receptacle. Cutting and engraving are different forms of the same operation. Both processes consist in the pressure of the finished vessel against the edge of a wheel revolving in a vertical plane, the incision being caused either by the hardness of the substance of the wheel or by the introduction of a cutting medium. In cutting, the rough incisions are produced by iron wheels of various sizes, with a medium of sand and water supplied by hoppers suitably adjusted; the rough incisions are smoothed by stone wheels supplied with a constant flow of water, and the patterns are polished by wooden (willow wood) wheels, with a medium consisting of water mixed with rouge or putty-powder.

The lathes in which the cutting wheels are adjusted are always driven by steam-power. Cutting wheels are of considerable size, ranging from 3 to 24 inches; they can, however, be removed from the lathe and others substituted without checking the machinery. The smoothing and polishing away of the mark formed at the base of a vessel by the seal of glass which formed its connection with the working-rod, and the process of stoppering are branches of glass-cutting. In the latter the mouth of the vessel to be stoppered is ground by an iron cone fixed to a lathe and

revolving in a horizontal plane; the shank of the stopper is ground upon an ordinary wheel, and finally the stopper is ground into the mouth of the decanter. The difference in effect of cutting and engraving lies principally in the depth of incision. Engraving wheels are copper discs ranging from 2 inches to $\frac{1}{8}$ inch. The engraving medium is a mixture of emery powder and oil, whereas rouge or pumice and oil are used, with leaden, wooden, or cork discs, for polishing. The wheels are adjusted in a small lathe, which is generally driven by a foot-treadle. In the Paris Electrical Exhibition (1881), an engraving lathe was shown driven by stored electricity. It is customary to leave the engraved pattern rough upon a smooth background, but the engraving may be polished and the background "roughed." Roughing may be most expeditiously effected by exposing the surface to be roughed to the abrading action of a constantly replenished descending column of sand. If it be desired to produce a pattern by this process, which is known as the sand-blast, it is only necessary to apply to the glass a stencil formed of some clinging material, which will protect the parts to be left clear, but leave exposed those parts which are to be roughed. Very delicate patterns may be thus produced, but although the abrasion may be of considerable depth, the depth is uniform throughout, and the pattern therefore lacks the force belonging to true engraving. Etching consists in the corrosion of the surface of glass by hydric fluoride. Patterns are produced by covering the whole surface of the glass with a thin coating of wax, removing the parts to be etched, and plunging the vessel into a solution of the acid. The removal of the wax is effected with great nicety by the use of a lathe and apparatus similar to that employed in turning a rose pattern on wood or metal.

Painting, Gilding, and Silvering fixed by heat.—Painting on hollow ware has not been much practised in this country. White and coloured enamels are used for colours, and an amalgam of gold or platinum or the powders of the same

metals reduced from solutions, are used respectively for gilding and silvering. The enamels have to be especially prepared, and must be rendered soft by the addition of borax: this is necessary, as the heat required to fuse an ordinary enamel would cause the collapse of the vessel upon which the painting had been applied. The pigments must be ground with a suitable medium, usually tar-oil or essence of lavender, until they are absolutely impalpable.

Carving.—In the Paris Exhibition, 1878, in the British section were exhibited some vases carved by hand labour. The substance of these vases consisted of two or more layers of different colours and the superior layers were cut through so as to discover in places the underlying material. The process is as follows: the design is marked out in Indian ink, and as much as is necessary of the upper layer is roughly removed by hydric fluoride in the manner already described. The actual carving, which is of excessive delicacy, is effected by small specially tempered steel gravers driven either by the unaided pressure of the hand or by the blows of a small wooden mallet. The ground is finally polished at an engraver's lathe with small wooden discs, pumice powder, and water.

CHAPTER XIII.

The Economy of a Lead Glass Manufactory.

OWING to the comparative costliness of the products of lead-glass manufactories, their locality has been less fettered by economical considerations than has been the case with the manufactories of the other branches of the trade. The proximity of coal and fire-clay, of water carriage, and above all of a ready market, has been principally considered. Lead-glass manufactories are therefore found at Stourbridge and Birmingham, on the banks of the Tyne and

Mersey, as well as in London, Glasgow, and Edinburgh. By the Factories Act (1878) no boy is allowed to be employed in a glass manufactory under the age of fourteen, and no male young person may work more than sixty hours in any one week. However valuable this regulation as to age of commencement may be for health, it is doubtful if it conduces to the proficiency of the future workmen. There are four grades or ranks, which are respectively known as that of boy, foot-maker, servitor, and workman or gaffer. It is rare for a boy to attain to the first rank in less than from ten to fifteen years. The names of the ranks are derived from the processes employed in the manufacture of a wine-glass. The "hands" of a lead-glass manufactory are divided into two sets or turns, which relieve each other at the end of every six hours; each set is made up of several groups or "chairs," the number of chairs being regulated by the number of crucibles. The usual complement is one "chair" in each set or turn to two crucibles, but varies with the size of the crucibles and the nature of the work. The number may also be increased by the use of auxiliary furnaces which supply heat for manipulation whilst the crucibles in the main furnace are recharged. Work commonly commences at 7 a.m. on Monday and goes on continuously night and day until Friday morning or evening, according to the condition of trade. On the Continent each chair consists of as many as eight persons. In England, one boy looks after the blowing-irons, carries vessels to be annealed, holds the "battledore," and runs errands, whereas on the Continent five boys are employed for the same work. The continental workman has always some one to assist him in shearing, and is so efficiently waited upon in other respects that he is never obliged to leave his chair: in fact, every provision is made to avoid needless waste of skilled labour. The system of payment in England is practically by the piece, but nominally by the hour, the unit being a nominal hour's work. A fixed value is placed on the nominal hourly produce of each member of a chair, the

value being proportionate to the rank of each. Whenever a pattern has to be reproduced in quantity, an agreement is made between the employer and workmen as to what number of vessels must be produced to be equivalent to the value of the nominal hourly wages. If in one hour's work the equivalent number of vessels be doubled or trebled, each member of the "chair" is entitled to double or treble of the nominal hourly wages. Thus, if the nominal hourly wages of a chair be respectively, workman 7*d.*, servitor 5*d.*, foot-maker 3*d.*, and boy $1\frac{1}{2}$*d.*, and the equivalent number of wine-glasses be 8, and if in one hour's work 24 of the wine-glasses be made, then the members of the chair will respectively receive for the hour's work 1*s.* 9*d.*, 1*s.* 3*d.*, 9*d.*, and $4\frac{1}{2}$*d.* By this arrangement the actual rate of wages remains unaltered, but the cost of labour is increased or diminished by raising or lowering the number of vessels equivalent to the unit of work. It is also customary in some factories to distribute at the close of each quarter a percentage upon the wages earned during the quarter, which offers an incentive to increase production.

Every boy when promoted to the rank of foot-maker is morally obliged to subscribe to and to become a member of the "Flint Glass Makers' Sick and Friendly Society of Great Britain and Ireland." The object of this society, as stated in a preface to the "Rules and Regulations," is to assist the unemployed members, to support the sick and superannuated, to aid the wives and children of the deceased, and to protect the rights and privileges of the trade from aggression. The society is generally well-managed and prosperous, and although certain of its regulations are vexatious to manufacturers, it cannot be denied that the increased sobriety and productive power of the workmen are due to the care exerted by the officials in excluding from the society persons who are likely to burden the funds. The sick and death rate of members of the society is exceptionally low.

The production of wares of high quality necessitates the

accumulation of disqualified glass, for which it is essential that profitable uses be found. Before discussing the possible uses of disqualified glass it will be convenient to review the stages of the production of lead glass from the raw materials. The raw materials are mixed, added to cullet or ladled glass, and thrown into the crucible. Purification consists in the escape of gases generated by the decomposition of the materials by heat, and in the rising of infusible matter to the surface. The skimming from the surface of the molten glass of the glass soiled by infusible matter, is the first contribution of disqualified glass. The second consists in the glass at the bottom of the crucible which is unfit for best work, and is generally removed by ladling, and mixed with fresh raw material. If a crucible break, the glass which runs into the furnace is utterly wasted, and the remainder can only be saved for future use by ladling. Blemishes are observable in glass, even when prepared with the greatest care. Discoloration may arise from a miscalculation of the probable heat of the furnace, the increased or diminished heat modifying the colour given to the glass by the manganic oxide. If the furnace be cold, the manganic oxide will remain unreduced, and the glass will be pink or "high-coloured;" if too hot, the manganic oxide will be entirely reduced, and the glass will be green, or low-coloured. Bubbles arise from disturbance or insufficient heat, specks from the corrosion of the crucible, striæ or cords from incorrect proportions of the raw materials, or more usually from variations in the temperature of the furnace. A wine-glass which has the slightest tinge of colour, which contains a bubble, a speck, or a cord, is disqualified. When glass is gathered, scales from the gathering-iron adhere to the glass in immediate contact with it. This glass, unless mixed with raw material and a considerable quantity of manganic oxide, is unfit for best work. For the manufacture of a wine-glass at least two, and often four distinct gatherings of molten glass are necessary. At each gather-

ing as much glass remains adhering to the iron as can be used, and the glass adhering to the iron is always more or less soiled as described. In annealing, in removing from the annealing ovens, in polishing, cutting, engraving, and packing, large numbers of vessels are daily destroyed.

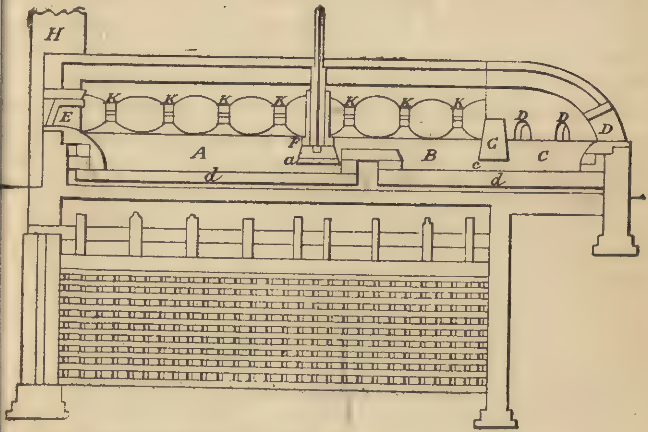
Such are some of the sources of disqualified glass. All disqualified glass is carefully collected and sorted. The best is mixed with raw material and re-melted; the second best, that to which scales of iron are attached, is similarly treated, but a proportion of manganic oxide is added to the mixture. The third quality is used for inferior ware, such as bottles, or for mixing with metallic oxides and conversion into coloured vessels. The fourth quality is also coloured, and may be used for making the coloured glass used for church and ornamental windows. There is, however, a fifth quality which is so mixed with fire-clay as to be unfit for use for transparent glass. This is ground to an impalpable powder, spread upon fire-clay plates or supports, and converted into opaque glass tiles. This final waste is commonly ground under an ordinary iron-shod mill-wheel, and is thereby discoloured. It is, therefore, necessary in making white or coloured tiles to place upon the fire-clay support, first a very thin layer of ground glass of superior quality, white or coloured, and then to add the other as a backing. This material is used for wall tiles as well as for a form of decoration known as opus sectile and for mosaic. The processes of working opus sectile and mosaics are similar. A working drawing is prepared, the material is cut or broken up, the pieces are fixed with glue face downwards upon the working drawing, and when a panel is complete the whole is backed up with cement. When the cement has become solid, the panel is turned over, the working drawing removed by washing, and the pattern discovered.

CHAPTER XIV.

Bottle Glass.

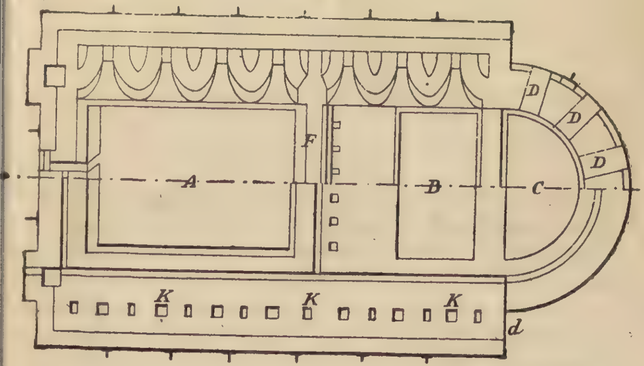
THE principle of the manufacture of moulded bottles is, that a mass of molten glass, expanded by the breath, assumes externally and internally the shape of any resisting surface with which it may be in contact. A moulded bottle must be cheap, strong, and must possess the power of resisting the corrosive action of ordinary fluids. Great economy of manufacture, great care in manipulation, and a scientific combination of raw materials will produce these essential conditions. The bottle manufacturer selects for his works a position which commands water-carriage, and a cheap supply of fuel. Economy in the consumption of fuel and the utilization of waste products as ingredients for the glass, must also be aimed at. It is of great advantage to the manufacturer if a supply of sand of sufficient purity be found in the neighbourhood. The construction of the furnace is the chief element in economizing the fuel. If an ordinary furnace be employed, large open crucibles are used, measuring from 2 ft. 6 in. to 3 ft. 10 in. in diameter. Large reservoirs or tanks, however, seem to be best adapted to this special branch of glass manufacture. The combination of gas furnace and tanks introduced by Dr. C. W. Siemens fulfils all requirements. On the old system, a crucible when emptied and recharged is useless for all working purposes as a source of heat, until the fusion of the fresh charge is completed. The fusion occupies from fourteen to sixteen hours, and the crucibles are emptied and refilled on an average five times weekly. The object of Dr. Siemens' system is to render the process of glass-making continuous. Fig 24 is a longitudinal section of an arrangement of tanks, A, B, C., and figs. 25 and 26 are respectively a horizontal and a vertical cross section of the same.

Fig. 24.



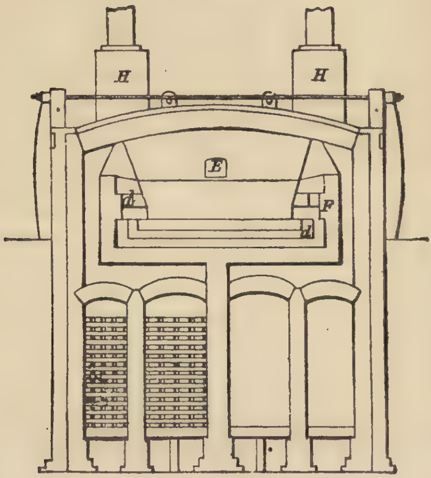
Longitudinal Section of Dr. Siemens's Tank Furnace.

Fig. 25.



The raw materials are received and partially fused in A, whence the liquid glass flows into the purifying tank B; on leaving this it passes into the working compartment C, from which it can be withdrawn in the ordinary way, through the openings D D, and which provides a constant source of heat for manipulation. The compartment A is charged through the aperture E, and is separated from B by a wall, F, in which are formed a series of passages, one

Fig. 26.



of which is shown at *a*. Through these passages the melted glass flows, and from B it passes to the tank C, through the passages, *c*, in the division wall, G. Floating divisions, rising and falling with the rise and fall of the molten glass, may, however, be substituted for the fixed divisions represented in the figures. The sides and bottom of the tank are perforated with air-passages, *d*, through which cold air is made to circulate by the draught

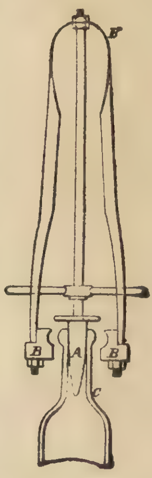
produced in the chimney, H; thus the tank walls are kept cool, and are enabled to withstand the pressure of the molten glass. The gas-ports are shown at K, and the heated air issues from corresponding openings. The advantages to be derived from the use of this arrangement are (1) increased power of production, as the full melting heat may be employed without interruption in one part, whilst in another part, through the perfect control of the gas and air supplied to the furnace, the glass may be allowed to settle and become sufficiently cool for working purposes. (2) Economy of labour in the operations connected with the fusion of the raw materials. (3) The durability of the tank and furnace. (4) Economy of fuel by the consumption of gas and air on the regenerative system.

The composition of bottle-glass is very varied; it generally consists of the silicates of sodium or potassium, calcium and aluminium, together with ferric oxide; it is to this latter oxide, present as an impurity in the cheap materials employed, that common bottles owe their green tinge. An analysis of a sample of French bottle-glass gives the following result:—Silica 53·55, potassic oxide 5·48, calcic oxide 29·22, alumina 6·01, ferric oxide 5·74. The materials employed for the manufacture of bottle-glass are granulated sand-stone or common sea or river sand; the residual alkaline and calcic salts from gas works, soap works, and alkali works; the sodic sulphate or salt cake; clay, basalt, and other rocks containing felspar, common salt, chalk; and, lastly, the slag from iron blast furnaces. The best quality of bottles are made from a mixture of sand, salt-cake, and chalk. The black bottles of Newcastle are made by substituting common salt for the salt-cake and additional ferric oxide is added to intensify the colour. Orange-coloured bottles are coloured by mixing manganic oxide with ferric oxide, and blue bottles by the introduction of a small quantity of the oxide of cobalt. Great credit is due to Mr. Bashley Britten for having devised a method of utilizing in the manufacture of glass

the iron slag which accumulates as refuse at the rate of nearly 8,000 tons per annum. Both the heat and the material of the slag are utilized, and it is upon the possibility of using the former that the economy of the process depends. The glass manufactory at Finedon in Northamptonshire is in close contiguity to the blast furnaces of the iron works; and as the molten slag is run out from the iron furnaces it is directly conveyed to the furnace in which it is converted into glass. The furnace employed is built on the continuous principle described, and alkalies and sand are added to the slag in the charging-tank. Bottle-moulds are made of either iron or brass, and whilst being worked must be maintained at nearly a red heat. A small aperture must be left in the lower part of every mould to allow the imprisoned air to escape whilst the hot glass is being introduced. A mould for a cylindrical vessel may be in one piece, but must taper slightly towards the bottom, to permit the delivery of the expanded glass. In order to form the neck of the bottle, the mould must be in at least two and usually in three pieces. The simplest form of a bottle-mould consists of two sides hinged together at the base. The objection to this description of mould is the fact that where the two sides of the mould join, a seam in the glass is always formed. This seam, however, is not noticeable when the bottle is square, and the join of the mould is at two angles of the bottle. Moulds in three pieces which are used for wine-bottles are made up of one piece for the body and two for the neck, the latter being hinged together above the shoulder. The seam down the body is thus avoided, although two slight seams are observable in the neck. Bottles are made by a "set of hands," which usually consists of five persons, respectively known as the "gatherer," the "blower," "the wetter off," the "workman," and the "boy." The simplest description of bottles, "medicals," are made in four processes, whereas other bottles require five. The glass being ready, whether in tanks or crucibles, the "gatherer" inserts the end of

his blowing-iron into the glass, and collects as much as he judges to be sufficient for his purpose; the "blower" now takes the blowing-iron, blows through it so that the glass becomes slightly expanded, and trundles it on a smooth iron slab until it assumes a conical form. He now opens the mould, inserts the conical bulb, closes the mould with his foot, and by blowing through the "blowing-iron" forces the bulb to assume both externally and internally the internal form of the mould. He now allows the mould to open, and removes the bottle attached to his blowing-iron. If it is a "medical" it is severed from the iron by tapping the latter on the edge of an iron tray, into which the bottle is allowed to fall, whence it is removed to the annealing kiln. If the bottle be large it is handed, whilst still attached to the blowing-iron, to the "wetter off," who detaches it by applying a moistened tool to the neck. The bottle is still without a lip, which it is the "workman's" business to supply. He holds the bottle either by an iron rod attached to the bottom by a seal of melted glass, or by a rod furnished with four prongs which surround and clip the body. He heats the neck of the bottle at an opening at the main furnace, or at a small auxiliary furnace, coils a small piece of molten glass round the neck, and then fashions it whilst still ductile with a tool especially adapted for the purpose. This tool is represented in fig. 27. A is a rounded projection which regulates the shape and size of the inside of the neck; C is a bottle in position; B B can be compressed upon the coil of hot glass by means of the spring-handle H, and together fashion the exterior of the lip. When the rim or lip is finished, the work-

Fig. 27.



Tool for Moulding the Inside and Outside of the Neck of a Bottle.

man either takes the bottle out of the prongs of the holder with a pair of wooden tongs, or separates it from the iron rod by sharply striking the latter. The "boy" finally carries the finished bottle on a fork to the annealing kiln. The kiln is kept at a temperature rather below the melting point of glass until completely filled, when the source of heat is allowed to become gradually extinct.

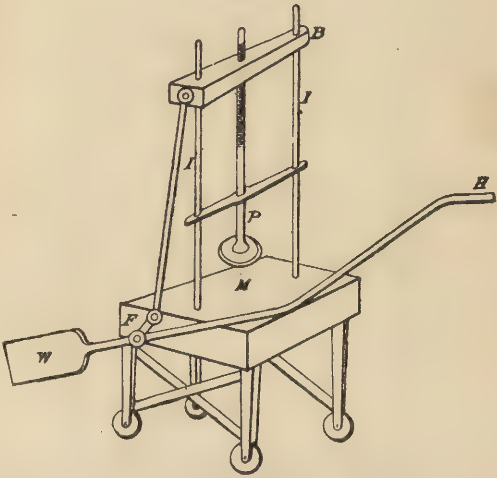
CHAPTER XV.

Pressed Glass.

THE general use of glass vessels for domestic purposes has been developed by the partial substitution of mechanical pressure for manual labour. In the process of moulding glass, the molten mass is forced to take the form of the mould, both on its inner and outer surface, by the pressure of the glass-blower's breath. In pressing glass, the molten glass takes the form of the mould, upon its outer surface, under the pressure of a metallic plunger, driven by mechanical means, whilst the form of the inner surface is modelled by the plunger itself. Pressed glass always requires to be polished by the remelting of an outer film, roughened by contact with the metallic surface of the mould. The roughness is probably caused by the comparative coldness of the mould, which produces shrinkage upon the surface of the hot glass. It is found that the hotter the mould can be kept, the smoother and brighter is the surface of the glass. Hand pressure can be applied to the production of small articles by attaching a rubber or plunger, by hinges, to the mould, so that the hinges may form the fulcrum, and the resultant pressure may be obtained between the fulcrum and the handle attached to the plunger. For work on a

larger scale, pressure is usually applied by a weighted lever, or a screw and fly-wheel. In the former (fig. 28) the mould is placed at M. A sufficiency of molten glass, gathered from the crucible by means of a blowing-iron, is dropped into the mould, and severed from the rod by the aid of a pair of large shears. By depressing the handle H, which turns upon a fixed axis, F, the frame B, sliding over the up-

Fig. 28.



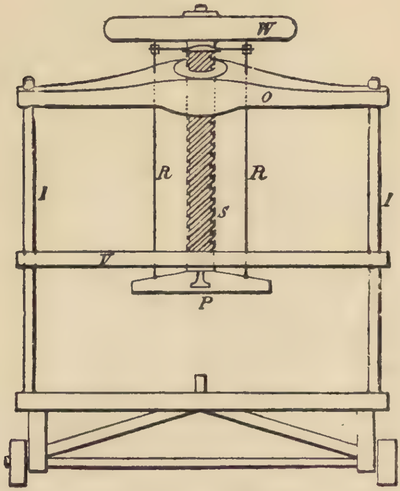
"Lever" Press.

rights, I I, together with the plunger, P, is lowered. The lever, H, is restored to its original position by the counterpoise, W. Fig. 29 represents a screw-press. By turning the fly-wheel, W, which is rigidly connected with the screw, S, and works in the fixed cross-bar, C, the plunger, P, is lowered, together with the rods, R R, and the bar, V.

The moulds are usually made of iron, brass, or gun-metal. The simplest form of mould is that employed for

stamping flat diamond-shaped pieces of glass for "quarry" glazing. In this case the mould merely consists of a flat slab of iron, with a slightly raised or depressed pattern, and of sufficient size to print two or more diamonds simultaneously. For articles of greater complexity, the moulds are made in two or more divisions, hinged together, and opening outwards by means of two handles, to facilitate

Fig. 29.

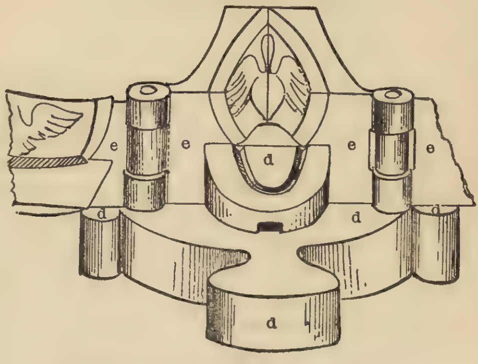


"Screw" Press.

the delivery of the glass. Fig. 30 represents the mould used in the manufacture of a pressed ornamental salt-cellar. The mould consists mainly of two pieces—viz., a base, *d*, and a collar, *e*. The collar is made up of three divisions, hinged together, as shown. The several pieces are so hinged together that the article can be liberated with the greatest ease, and the joints are so fitted that

the glass may be as little marked by them as possible. The bases of hollow vessels, after removal from the annealing kiln, require to be smoothed and polished. In the manufacture of pressed glass a considerable saving has been effected, both by the substitution of unskilled for highly-trained labour, and by the use of cheap materials. The pressed-glass manufacturer's aim is to produce a glass rivalling lead-glass in whiteness and clearness, but at the same time surpassing it in softness and in its power

Fig. 30.



Mould for a Pressed Glass Salt Cellar.

of retaining heat. At one time the same ingredients were used as for lead-glass, with the addition of a considerable proportion of borax. Red-lead, the costly ingredient of lead-glass, has recently been replaced in pressed glass by the carbonate of barium : the resultant glass being a mixture of the sodic and baric silicates. Another raw material used for pressed glass is cryolite—a compound of hydric fluoride, water, and the sodic and aluminic oxides. If 4 parts cryolite be added to 1 of oxide of zinc and 10 of sand, a milk-white opal will be produced, transparent for

light rays, but cutting off the red. If a smaller quantity of cryolite be added, a white transparent glass will be the result, of great brilliancy, strength, and refractive power. If, on the other hand, more than 4 parts of cryolite be used, an opaque mass will be obtained, which in appearance closely resembles china or glazed earthenware. This opaque substance, either white or coloured, is now pressed into a great variety of useful and ornamental articles.

CHAPTER XVI.

Glass Mosaic for Windows.

THE words "glass mosaic" give a more accurate description of the true nature of a window, the colours which are due to the colours of the constituent glasses, than the expressions so commonly met with, "stained" or "painted" glass. Excellent effects can be produced without the use of either stain or paint, and the use of the latter should in all cases be as limited as possible. By the term "paint" is meant an enamel colour fused to the surface of glass by heat: no account being taken of the use of ordinary pigments, which is quite illegitimate. By the term "stain" is meant a transparent and permanent effect of colour, produced by the action of heat upon certain metallic oxides, applied as pigments to the surface of the glass. The mosaic method is simply the representation of the different colours of a design by different pieces of coloured glass, the pieces of glass being bound together by strips of doubly-grooved lead. The first step in the manufacture of a mosaic window is the preparation of a small design to scale of the completed work. According to the general features of the sketch, a full-sized drawing or cartoon is prepared. If the human figure be introduced, separate studies are made from life, and spaces are left for

their insertion in the cartoon. From the cartoon and studies a working plan is obtained by tracing upon transparent cloth. Upon this working plan are marked numbers, indicating the coloured glasses to be employed, the outlines of the shapes to which the glasses are to be cut, and the position of the connecting leads, as well as of the iron bars and stanchions which are provided to support the finished window. The working plan first passes into the hands of the "cutter," who shapes the pieces of glass which have been selected for use. The glass generally used for the purpose is in the form of either "sheets" or "crowns." The sheets and crowns, however, are smaller in size, but thicker in substance, than those used for ordinary glazing. The manipulation of crowns or circles of both coloured and plain glass is identical. The advantages in the use of circles are (1) the variety of tints contained in a single piece of glass, owing to the irregularity of its substance, and (2) the possibility of using the glass immediately after annealing, the necessity of flattening being avoided.

The manipulation of coloured sheets is slightly modified, in order that the cylinders may be perfected before annealing. This is effected by opening out the end of the bulb remote from the blowing-iron, and attaching it temporarily to a flattened circular mass of glass carried by a working-rod; the bulb is then severed from the blowing-iron, and the workman, grasping the working-rod, opens out the narrow severed end of the bulb, so that the two ends may be equal and the sides parallel. The cylinder thus formed is detached from its temporary base, annealed, cut through with a diamond, reheated, and flattened. Sheets or circles may be "cased" or "plated" with one or more different colours. If the thin layer or casing be removed by the action of hydric fluoride, the colour of the background may be revealed. Cased glass, treated in this manner, is valuable for the representation of heraldry. "Splashed" or "sprinkled" glass is formed by rolling the

solid mass of molten glass in fragments of differently coloured glasses, expanding the mass into a bulb, and fashioning it into a sheet or circle. A sheet of glass marked with depressed irregular lattice-lines, is formed by inserting the partially-expanded bulb into a mould with projecting ribs, forcing the bulb to accept the impression of the ribs, and then twisting the depressed lines thus produced. The "roundels" or "bulls'-eyes," so largely used in domestic glazing, and intended to represent the centres of crown-glass, are made in the same manner as crowns or circles, but on a liliputian scale. Hartley's rolled coloured-plate, and quarries stamped by mechanical pressure, are also largely used where translucency is required without transparency.

The artist selects the glass for the "cutter," who places it over the working drawing, arranged upon a strong transparent glass-desk, and marks out the shapes with a diamond. Fracture is caused by sharply striking the back of the glass, and minute alterations of curvature are effected by means of pliers. If the window is merely an ornamental arrangement of differently coloured glasses, the shaped pieces of glass pass immediately from the "cutter" to the "glazier." By the glazier the shaped pieces are united together with strips of doubly-grooved lead, and the joints of the lead are securely soldered. The leaden strips are formed from rough castings by mechanical pressure. The vice used for this purpose consists mainly of two slightly-indented wheels, revolving one above the other, between which the lead is gradually drawn inwards, elongated, and crushed into shape. When a complete panel of glass has been formed and surrounded by a grooved-lead stronger than that employed for uniting the constituent fragments, the adhesion of the glass to the lead throughout the entire panel is secured by temporarily raising the edges of the lead and rubbing in a cement, consisting of white lead and boiled oil. If the design of the window requires the introduction of shading or outline, or of the

tints which can be produced by means of stains, the shaped pieces of glass pass from the cutter to the artist, from the artist to the kiln, and from the kiln to the "glazier." The artist places the pieces of glass over the original cartoon, supported on a glass-desk, and traces in the outline with a dark-coloured enamel; he then temporarily fixes the pieces on a glass-easel, by means of a mixture of melted wax and resin, and introduces any shading, high-lights, or stain that may be required. The transparency of the easel renders it possible for the artist to judge, in some degree, of the effects he is producing. The pieces of glass are finally severed from the easel and embedded in plaster of Paris, on the iron shelves or on the bed of the kiln, described at pages 49 and 50.

The enamel used by the glass-painter for shading and outlines is a fusible glass containing a sufficient quantity of an infusible powder to produce the effect of opacity. The opaque substances most commonly used are ferric oxide, cobaltic oxide, and manganic oxide. The oxide of iridium is too costly to be generally made use of. The glass fixative must be more fusible than the glass back-ground, but at the same time must be perfectly durable. Glasses containing borax must be carefully avoided. The borax is only rendered temporarily anhydrous by fusion, and after exposure to weather becomes hydrated and efflorescent and causes the decay of the enamel, and the consequent disappearance of the artist's work. Bought enamels should be roughly tested by moistening a small quantity with hydric sulphate, diluting with pure alcohol, warming and igniting. If when the flaming mixture be stirred the flame acquires a greenish tinge, the presence of borax may be assumed. A glass formed in accordance with the formula K_2O, PbO, $4SiO_2$, will be found sufficiently fusible as a fixative, and will resist atmospheric corrosion. The glass is melted in a crucible and when thoroughly fused poured into cold water, by which it is crumbled into fragments. It is best to reduce the brittle

material thus obtained to a coarse grit in a mill, and then to grind the grit to an impalpable powder on a glass slab with glass mullers. The glass-powder is finally mixed with the infusible oxide and re-ground with a medium, generally consisting of tar-oil. The enamel is applied with a brush as an ordinary pigment, and is permanently fixed to the surface of the glass background by exposure to the heat of a kiln. Shadows may be represented by one of three methods: (1) by enamel applied in a mass, known as "smear" shading; high lights are introduced by the removal with a point of parts of a smear shadow: (2) by thin interlacing lines, known as "cross hatching:" (3) by a mass of colour allowed partially to dry and then disturbed by the friction of a soft-haired brush, known as "stipple shading."

Stains.—The two stains employed are produced respectively by argentic and cuprous oxide—the use of the latter, however, is rare. The oxides are mixed with an infusible medium, such as kaolin or ferric oxide, moistened with water or tar-oil, and applied as pigments. The colour of the silver stain varies from a pale canary to a deep orange, according to the quantity used. By some manufacturers the use of the soluble nitrate is preferred to the oxide on account of the facility with which it can be mixed, and its strength regulated. The ruby stain due to cuprous oxide requires a reducing flame in the kiln and the admixture of reducing agents.

CHAPTER XVII.

Artistic Treatment of Mosaic Glass for Windows.

FOR the right use of the mosaic-enamel method in the production of modern windows, it is necessary for the architect, artist, and manufacturer to study the possibilities of manufacture, the capabilities of the materials, the effects

presented by ancient examples, and the requirements of the situations which the windows are intended to occupy.

Possibilities of Manufacture.—The mosaic method necessitates the use of lead-lines, cross-bars, and stanchions. In pattern windows they may be utilized to accentuate the design, and although their presence makes it necessary to conventionalize natural foliage, which should form the basis of all except purely geometrical and architectural ornament, this very conventionalization makes the ornament harmonize more completely with the material. In picture windows the question arises as to whether the lead-lines and bars are to assist in the design or to be disregarded. It seems to be best that the bars should be disregarded, provided they do not cross the face of the subjects represented, or cut up the picture into geometrical shapes. If they are present in sufficient numbers the eye is not distracted, and merely derives an agreeable impression of the strength and stability added by them to the window. In the representation of the human figure lead-lines may either act as outlines, or form part of a dark background. The latter is probably the most pleasing arrangement.

In considering the capabilities of materials—*i.e.*, of glass and enamel, it will be convenient to examine their relations to light both with respect to colour and translucency. At this point the study of ancient glass becomes of value, for it is necessary to discover to what cause or causes are to be attributed the effects of colour possessed by some of the most ancient windows. It is generally stated that decay has mainly contributed to produce the effects alluded to. Decay undoubtedly tends to harmonize the colours of glass, but there are specimens of ancient glass which show no signs of decay, and which nevertheless, possess a softness and depth of colour which have seldom been attained by modern manufacturers. Various attempts have been made to imitate old glass artificially (1) by irregular smears and dots of enamel colour; (2) by abrading the

outer surface of modern glass by mechanical means, or by hydric fluoride. Such methods produce at the best an unsatisfactory result, and are to be deprecated, except in cases where repairs are needed to ward off destruction from ancient windows. The effect of old glass lies deeper than the surface, and depends upon its chemical and physical nature. The artists of ancient days used for their glass sea or river sand and wood ashes, and were not too particular about chemical proportions. Their glass contained no lead, no borax, and no oxidizing and cleansing ingredients, and was fused in open crucibles with wood fuel.

Ancient glass resembles in its physical nature horn rather than glass. It is translucent, but neither appreciably refracts or disperses the rays of light, merely sifting them and suffering them to pass. If it is desired to produce glass similar to the old, it is absolutely necessary to imitate the imperfections of ancient glass manufacture. The great fault in modern glass windows is the harshness and want of harmony of the colours, as well as the apparent thinness of the glass. The effect of thinness and harshness is due to the purity of materials, the equality of the substance, and to the refraction and dispersion of light.

It is necessary now to consider how coloured glasses are to be arranged in a picture window in respect to their depth of colour and what subjects are suitable for representation. By a "picture window" must be understood one into which one or more human figures are introduced upon a suitable background. It seems to be desirable that the background should be dark in order to absorb the leaden outlines of the figures, but it is undesirable that the figures should show up as white patches upon an obscure screen. The only admissible treatment of pictures in windows, owing to the nature of the materials, is a flat treatment. Atmospheric effects, perspective, and landscape, should be introduced sparingly and with caution. Landscape is especially to be avoided, owing to the limited

range of colour, and the stiff outlines rendered necessary by the mosaic method. The most suitable and pleasing arrangement is that in which the figures are represented as exposed to a full sunlight and as standing in front of a curtain or a flat screen of foliage or architecture, the openings in which may convey an idea of distance beyond the screen.

It has already been pointed out that enamel paint, except when used sparingly, tends to interfere with the translucency of a window. The methods of using enamel paint for shading have already been alluded to, and there can be little doubt that the more transparent the shadows are, the better is their effect. The use of enamel paint grew with the deterioration of glass for artistic representation. By artistic deterioration must be understood the improvement in the purity of colour and in the regularity of substance. A study of the most ancient examples of pictorial windows demonstrates the immense economy observed in the use of enamel. The enamel is certainly not missed, for the effects obtained by the brush are more than compensated by the variety and apparent substance of the ancient glass. Although it is unquestionably desirable to imitate the most ancient windows in the nature of their glass, and in the economical use of enamel, it is not therefore to be inferred that it is necessary to imitate the imperfections of ancient drawing. A modern window should be historical and representative of the best available art of the time at which it is erected. In designing windows it is necessary to remember the essential use of windows, and to adapt the designs to the aspect and atmosphere and to the amount of light it may be desirable to admit. Care must be taken that windows inserted in a building shall not clash with the architecture, or with other windows already in position. It is not necessary to reproduce in a new window the particulars of the old, but it is desirable that the general scheme of colour and arrangement existing in the old, *should* be adopted in the

new. The following are a few of the characteristics (especially with regard to the use of enamel colour, and to the nature of the glass) of the different styles or periods of ancient mosaic glass windows. Mr. Winston divides the history of mosaic windows into five periods, viz. :—

1. Early English: from the earliest specimens to 1280.
2. Decorated: from 1280 to 1380.
3. Perpendicular: from 1380 to 1500.
4. Cinque-cento: from 1500 to 1550.
5. Intermediate: from 1550 to the modern revival of mosaic glass.

1. *Early English.*—The glass possesses an effect of depth, richness, and strength produced by the irregularity of its substance.

The ruby is exceedingly rich and irregular, in some parts almost black.

The blue possesses a sapphire tint.

The white varies from pure white to sea-green.

There is a great variety of pinks and purples, and a yellowish pink-glass is used for flesh. The yellow is never orange, but varies between a cold canary and a rich gold.

The figures are disproportionately tall and slender, and the draperies are stiff and close, and full of small folds. The foliage is unnatural. The pictures are generally contained within variously shaped coloured panels with narrow edgings or borders.

The smallness of the figures and the minuteness of the pieces of glass give to the windows when viewed from a distance merely the effect of a rich and confused assemblage of colours. Enamel is very sparingly used, shading is effected by cross-hatching and occasionally by "smear."

2. *Decorated Period.*—The glass has a less substantial appearance. The ruby-glass is more regular, and the blue less deep—a cold emerald green is introduced The white

is generally a rich sea-green, but becomes lighter in later examples of the same period. The yellow silver stain appears (introduced soon after the commencement of fourteenth century). The flesh-colour is paler and yellower than in the early English style. Cross-hatching shading is gradually abandoned—the "smear" method of shading becomes common. The figures are better proportioned; the foliage is natural, that of the oak, maple, and ivy being easily recognized.

3. *Perpendicular.*—The white glass acquires a cold greenish-blue tint, but changes later in the period to a cold yellow-green. The ruby is lighter, and approaches a scarlet colour. The ruby coating is considerably reduced in thickness. The practice of abrading the ruby, so as to leave spots of white upon a red ground, is introduced. The blue glass is generally of a soft purple hue, but sometimes of a cold steel grey. Towards the close of the period coated blue glass appears. The yellow stain is sometimes used to heighten the colour of yellow glass. A slight wash of enamel colour upon white glass commonly represents flesh. Enamel outlines become narrower and weaker, and stipple shading almost entirely supersedes the "smear" method. Figures are more refined and by degrees assume just proportions. The foliage is conventional.

4. *Cinque-cento.*—Many new tints of pink and purple appear. A very light blue is largely used, and is often converted into green, or dark yellow, by staining. Sprinkled ruby is introduced. The white glass is almost colourless, except for a slight yellow tinge. The enamel wash on white glass is entirely used for flesh. Stain is used in great profusion on white as well as on coloured glasses. Deep enamel outlines are employed to assist deep shadows. Shadows are generally produced by stippling, but "smear" shading is much employed in ornament. The heightening of the effect of shadows by cross-hatching is gradually superseded by the application of dense opaque dabs of unstippled

paint. A warm brown colour for shading is introduced. The figures are exquisitely finished, and are often dignified and full of character. The features are expressed rather by lights and shadows than by outlines. The heads of the larger figures bear a considerable resemblance to those appearing in oil paintings of the same period. Ornament is borrowed principally from Roman arabesques, and is executed upon white glass, enriched with yellow stain. The occurrence of coloured wreaths, garlands, and festoons is common. Each picture is generally framed in a mass of ornamental work.

5. *Intermediate.*—This period is chiefly characterized by the increased use of enamel, and by the imitation of the effects of oil paintings.

ON THE MANUFACTURE OF CROWN AND SHEET GLASS.

BY HENRY CHANCE, M.A.

THE two kinds of window-glass, which are known by the names of crown and sheet, are derived from a mixture of ingredients, the chief of which are sand, sulphate of soda, and chalk or limestone.

The first of these three materials constitutes more than one-half of the whole mixture. The cost and quality of the sand employed are therefore of great importance. France and America are fortunate in possessing sands free from oxide of iron, but they are too expensive, when imported into this country, for ordinary window-glass. The Belgian manufacturers draw their supplies of sand chiefly from the neighbourhood of Waterloo. This sand contains a small quantity of oxide of iron, but Moll, about thirty miles from Antwerp, furnishes a sand which is comparatively free from this defect.

There are various sources in England of sand suitable for glass-making. That which is used in the manufacture of crown and sheet glass is derived chiefly from Lancashire, where it lies close to the surface, in shallow beds of great extent, and from Bedfordshire, where the strata vary from five to forty feet in thickness. The glass works on the north-east coast draw their supplies from Belgium, the cost of transport being very small.

The sands of Lancashire and Bedfordshire are not free from oxide of iron, but they are much purer than they

appear to be. The former is brown, from the presence of organic matter; while the latter is often of a yellowish tint, from the admixture of loam, which forms part of the stratum, and which in digging the sand cannot be separated from it.

The whiteness of sand, however, is by no means a certain test of its purity. Sand having a strong reddish hue may be made white by calcining it with a small quantity of common salt, but the iron is still present. Analysis also will often fail to detect a difference between one sand and another, which will become very apparent upon actual trial. The sandstone of Wales, of which there is an abundant supply, does not differ in its component parts from that of Bedfordshire, but it yields a glass inferior both in colour and quality.

Sand which does not contain more than half a per cent. of oxide of iron is sufficiently pure for ordinary window glass. If earthy or organic matters are mixed with the sand, they can be removed by washing it; whether washed or not, it is generally heated to redness before being used. Stones or large particles are removed by passing the sand through wire sieves, either in the process of washing or after it has been heated.

The next important element is soda, which is used in the manufacture of all kinds of window glass in preference to potash, as being the cheaper of the two. The adoption of sulphate of soda is of comparatively recent date. The substitution of carbonate of soda, manufactured from common salt, for the crude alkalis derived from the combustion of marine plants, and of sulphate of soda for carbonate, constitute the most important changes that have been made in the chemical part of the manufacture of window glass. Not much more than fifty years have elapsed since crown and sheet glass obtained their alkali from the ashes of a certain sea-weed, known in this country by the name of kelp. The preparation of kelp for this purpose employed a large population on the northern

shores of Scotland and the west of Ireland. The kelp was used in combination simply with sand, containing in itself both soda and potash, and furnishing the lime necessary for the composition of the glass. The glass thus produced was of a very variable character, arising from the uncertain quality of the raw material, and also of a very inferior colour, evidence of which is still to be found in the old windows of ancient houses.

A similar crude alkali was employed in other countries, under the name of barilla, soda of Alicant, &c.; and at Venice, and in the south of France, this was mixed with a natural product, called the natron of Egypt, and containing carbonate, sulphate, and muriate of soda.

The discovery of Le Blanc in 1792, which effected the conversion of common salt into carbonate of soda, was the commencement of a new epoch in the history of window glass. The manufacturers of soap at Marseilles ceased to import the soda of Alicant, and employed this new alkali in its place. Their example was followed by the manufacturers of plate glass, and before long the use of the old crude material was discontinued in the preparation of window glass, to the benefit both of its colour and quality.

The alkali thus substituted was the carbonate of soda of commerce, containing, besides carbonate, a considerable quantity of undecomposed sulphate. The further improvement which followed, namely, the substitution of sulphate of soda for the carbonate of commerce, was due to the researches of the celebrated Gehlen; but some time elapsed before his ideas were carried out in Germany, and it was not until 1825 that the manufacturers of France, released from the veto which the Government had pronounced on the sale of sulphate of soda, were enabled to turn their attention to the cheaper article.

They proceeded with caution in the introduction of this new ingredient. Mixing a small quantity of sulphate of soda with a large proportion of carbonate, then half of each, and, finally, excluding carbonate, they used

sulphate only, to the injury, doubtless, of the colour of their glass, but gainers by the employment of a cheaper and more manageable material.

The introduction of carbonate of soda, prepared from salt, into the glass manufacture of England, dates from the year 1831. Proceeding cautiously in the steps of their foreign brethren, the English glass-makers, after they had established the use of carbonate, made trial of the effect of a small quantity of sulphate mixed with it. The carbonate gradually decreased, until at length in the preparation of blown window glass sulphate stood alone. The greenish-blue tint of glass made from sulphate of soda, though of little importance in crown and sheet glass, formed an apparently insuperable obstacle to the adoption of this material by the manufacturers of plate glass. This tint was ascribed by chemists generally to the action of the carbon necessary for the decomposition of the sulphate. M. Pelouze, on the other hand, was of opinion that it was entirely due to the presence of iron, derived mainly from the common salt used in the preparation of the new material, and not eliminated by any subsequent process. His researches proved the correctness of his theory. He succeeded, with the aid of lime, in removing every trace of iron, and the result was a refined sulphate of soda which yielded glass as pure in colour as that made from carbonate, and which is now employed generally by the manufacturers of plate glass.

Glass made with sulphate of soda is less liable to devitrify, or, as it is termed, to become "ambitty" in the pot during the time of working, and will, therefore, bear a larger proportion of lime than carbonate glass. This is of great advantage, as from the increased quantity of lime, the glass is harder, takes a better polish, and is less liable to the exudation on its surface which is technically termed "sweating." The use of sulphate of soda involves the introduction of an ingredient which is not required where pure carbonate only is employed. This ingredient

is carbon, which is introduced in the proportion of one or rather more than one equivalent to two equivalents of sulphate. The carbon abstracts from the sulphate one equivalent of oxygen; the sulphurous acid which is thus formed is displaced by the silica, and silicate of soda is the result. No fixed proportion of carbon seems necessary for the decomposition of the sulphate. At least 25 per cent. of the quantity ordinarily used may be withdrawn for a time without interfering with the quality of the glass, and it has been found that glass can be made with sand, sulphate of soda, and carbonate of lime without any carbon whatever. The experiment was conducted in a covered pot to exclude the possibility of any carbon being introduced into the materials from the fuel of the furnace. There was indeed in this case considerable difficulty in reducing the materials to glass, and a large amount of undecomposed sulphate remained floating on the surface of the metal, but a sufficient quantity of it had been decomposed to form a transparent glass. The result would seem to show that the decomposition of the sulphate is not wholly dependent on the carbon employed, and that it is materially assisted by the third ingredient, carbonate of lime, of which I shall speak presently.

To replace sulphate of soda by chloride of sodium in the manufacture of glass, and thus to dispense with the process of converting the latter into sulphate, and with the subsequent waste of the sulphuric acid used in the process, is a problem which has long engaged the attention of chemists. The well-known invention of Mr. Gossage consisted in passing chloride of sodium in the state of vapour, and mixed with steam, through a tower filled with flints heated to whiteness. Silicate of soda, and hydrochloric acid were produced; the former flowed downward in a melted state, the latter passed upward. I believe I am correct in stating that the silicate of soda formed by this process has not superseded either sulphate or carbonate in the manufacture of glass.

About fourteen years ago some very interesting experiments were made by the eminent chemist, Mr. George Gore, in reference to the production of silicate of soda from common salt in the glass pot itself. Mr. Gore devised a mixture of materials in which steam should be liberated throughout at a high temperature only, and therefore under the conditions most effective for decomposing the salt. In this mixture, sulphate of soda and carbon were dispensed with altogether, and they were replaced by a chemically equivalent mixture of hydrate of soda and common salt, these two ingredients being also in quantities chemically equivalent to each other, and representing together as nearly as possible the amount of alkali contained in the ordinary sulphate mixture. The mixture thus modified consisted of sand, cullet, or waste glass, chalk, common salt, hydrate of soda, arsenic, and manganese. In the reaction which took place the hydrate of soda decomposed the salt at high temperatures, and formed hydrochloric acid and anhydrous soda. The former escaped as gas, the latter united with the silica. Mr. Gore succeeded in obtaining by this process a transparent glass, but the cost of the caustic soda rendered the mixture more expensive than with sulphate.

The third important ingredient in crown and sheet glass is lime, which in glass made with sulphate of soda is almost invariably introduced in the shape of chalk or limestone. In carbonate glass either caustic lime or carbonate of lime may be used. It is a curious fact that while as regards the quality of the glass, chalk and limestone are found to answer equally well, glass made from the latter is harder and more difficult to grind than that which is made from the former. This may perhaps be due to the carbonate of magnesia which is generally present in limestone, but in a much smaller degree in chalk. Limestone possesses, moreover, the property of causing the glass to cool and set more rapidly when worked into shape. When chalk or limestone is added in excess, the glass becomes hard and difficult to work, and is liable to devitrify.

Although glass can be produced from sand and alkali without any other ingredient, lime is a very important element, giving to it hardness and insolubility.

In flint glass lime is replaced by lead, which imparts a far greater brilliancy, but at the same time, owing to the difference between its specific gravity and that of the other materials, is the cause of innumerable striæ. A lump of the purest and most beautiful flint glass would, if made into a sheet, be so full of these striæ as to be utterly worthless. On the other hand, a vessel made of the very finest crown glass is dull in colour, and is altogether wanting in the brilliancy which characterizes lead glass. Of carbon, as necessary for the decomposition of sulphate of soda, I have already spoken. Anthracite coal is the form in which it is generally introduced into the mixture for crown and sheet glass. As anthracite is seldom absolutely free from iron, charcoal is preferred where purity of colour is an essential element in the glass.

Some manufacturers employ in their mixtures small quantities of arsenic and manganese. The former assists in oxidizing any carbonaceous impurities that may be present, and in promoting the decomposition of the other materials. The latter peroxidizes and thus reduces the colouring property of the oxide of iron, which is to be found in a greater or less degree in one or more of the materials. But there is a manifest inconsistency in employing in the same mixture carbon as a reducing and arsenic and peroxide of manganese as oxidizing agents.

Many of the manufacturers of sheet glass on the Continent dispense with both these ingredients. It was formerly the custom in some glass works to add to the mixture alumina in the shape of pipeclay. This addition did not produce any beneficial result. Alumina is always present in glass, owing to the action of the alkali on the clay of the pots, or of the furnace, if there are no pots and the materials are melted in the furnace itself. A pot is not unfrequently attacked to such an extent that the

alumina mixed, but not amalgamated with the glass, appears in it in the form of knots and veins, and seriously interferes with the quality. When this happens the only remedy is the substitution of a new pot for the old one.

To complete the mixture a certain quantity of waste glass, or cullet, is added. This keeps the materials open, and, being more fusible than they are, assists the operation of melting.

The same mixture may be used both for crown and sheet glass. To lay down, however, any standard proportions is almost impossible, as no two manufacturers use the same. Even in the same works the melting powers of the furnaces may so far differ as to render necessary, for the production of the same glass, variations in the proportions of its elements. The size and thickness of the pots employed are also points which have to be considered in determining the mixture. There is, I believe, a notion prevalent among chemists that glass manufacturers mix their materials in a sort of haphazard way, without any reference to equivalents. It must be borne in mind, however, that a scientifically compounded mixture, which may readily be converted into pure glass in a laboratory, may prove utterly impracticable when tried on a larger scale. The chemist, having at his command the most intense heat and vessels that are indestructible, may make use of materials and proportions which, before they could be reduced to glass, would melt down the pots and furnace of the manufacturer. The latter, on the other hand, being limited in the composition of his melting vessels, has to use that mixture which will produce the best results compatible with their safety. In other words, as he cannot adapt his pots or furnace to suit his mixture, he must adapt his mixture to suit them. When, after long experience, he has arrived at the proportions for his glass which are most in accordance with the size of the pots, the construction of the furnace, and the heat obtainable, he

will find that the mixture will admit of only very slight modifications. He may, from time to time, use a little more or a little less alkali or lime, but, before long, he will probably revert to the former proportions. It is obvious that, with each change in the composition, the component parts of the waste glass, or cullet, are also changed. Frequent changes will thus produce cullets differently constituted, and will make it almost impossible to refer particular defects to a given mixture.

The various ingredients which I have mentioned having been thoroughly incorporated together, are, without further preparation, introduced into the pots in which they are to be melted. During the period in which barilla, kelp, and other forms of crude alkali were in use, it was the custom to subject the materials to the preliminary operation of fritting, or stirring them together in a reverberatory furnace, thereby effecting partial decomposition, and burning off any carbonaceous impurities. The adoption of alkali prepared from salt has removed the necessity of this treatment. The pots are made of the best fire-clay, and are distinguished from flint-glass pots by the absence of any wood or cover to protect their contents from the fire.

In France and Belgium, where the same furnace is generally used both for melting and blowing, and only one blower is attached to a pot, the size of the pot is limited by the number of pieces which a man can blow at one time. In the English sheet glass works there is, where pot-furnaces are used, a separate furnace for blowing, and as a pot may thus serve two or more blowers, it can be of much larger dimensions than under the foreign system. The average outside diameter of a Belgian pot at the top is, at the present time, about 48 inches, that of an English one ranges from 42 to 65 inches.

The foreign pots are made in moulds of thick wood, strongly hooped with iron. A round mass of fire-clay, about 10 or 12 inches thick, forms the bottom of the pot.

Round this is placed the mould, lined with strong cloth, to prevent the adhesion of the clay, and the lower portion of the sides of the pot is formed by beating down the middle of the mass of clay, and forcing up the outer portions against the sides of the mould, the original thickness of the bottom being thus reduced to about 4 inches. The remaining portion of the pot is completed by building it up with rolls of clay worked by the hand against the sides of the mould, the thickness gradually diminishing towards the top of the pot.

English pots are made without the aid of moulds. The sides are formed with rolls of clay, as in the case of pots made in moulds, but the left hand of the workman takes the place of the mould, and supports, on the outside, the wall of the pot, while he builds it up on the inside with his right. Pots made entirely by hand require more skill on the part of the maker, but the result is more satisfactory.

In whatever way they may be made, the pots have to be carefully dried for some months, and then to be prepared for the furnace by a preliminary heating in a kiln or pot-arch. When they have attained there the requisite degree of heat they are conveyed on a machine to the glass-house, and set in their places on the floor of the furnace, the old ones having been previously removed. As the temperature of the furnace is tolerably high, the operation of taking out and putting in pots is rather a formidable one.

There are two kinds of pot furnaces in use for the manufacture of crown and sheet glass, namely, the old style, which we may call the coal furnace, in which the fuel is placed on grates within the furnace itself, and the regenerative furnace of Dr. Siemens, which is worked by gas. The former is now little used in England, having been almost entirely superseded by the gas furnace, but it still retains its place in Belgium, where the works carried on under the old system greatly outnumber those under the new.

The coal furnace is a rectangular chamber, with an arched

crown or roof, large enough to contain six or eight pots in two parallel rows, with sufficient space between the rows to admit of a grate-room at either end of the furnace (*vide* fig. 1).

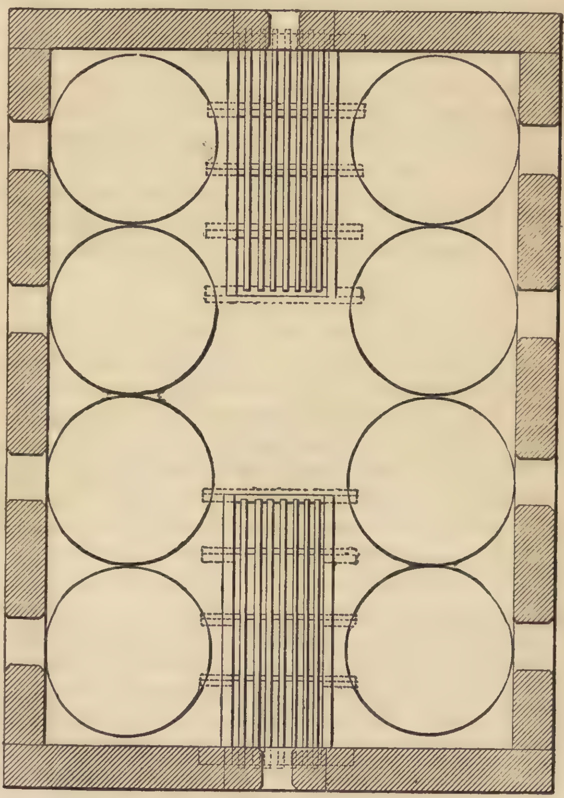


FIG. 1.

These grate-rooms are sunk several feet below the level of the bed of the furnace, and are separated from each other by a portion of the bed, which is called the flag. On this

bed are placed the pots, each one being close to or a few inches distant from its neighbour in the same row. In front of and above each pot is an aperture in the wall of the furnace, through which the melted glass is withdrawn. On the Continent, where, as I have stated, the melting furnace serves also for blowing, there is a large cavity on each side of the furnace, over which are placed platforms or stages on which the blowers work.

The process of heating a coal furnace is comparatively simple. The main points to be attended to are to cover the grates well with fuel, so as to prevent injury to the pots by the admission of air, to supply the fuel at short intervals, in order that as uniform a temperature as possible may be maintained, and not to allow an undue accumulation of cinders on the grates.

The flame passes over the pots, and through the apertures in the walls of the furnace into the cone or chimney, or lantern in the roof, which covers the furnace.

The obvious loss of heat which this system entails led Dr. C. W. Siemens and his brother Mr. F. Siemens to turn their attention to the application of the regenerative process to the melting of glass. In the year 1861 one of the English manufacturers erected a furnace, on the new system, for the manufacture of sheet glass.

Prior to this date attempts had been made to use, for the purpose of melting glass, gas produced in an apparatus apart from the furnace, in place of fuel placed in the furnace itself. M. Bontemps states that, about the year 1850, he saw in operation at Zwikau a gas furnace invented by M. Frickentscher. It contained eight pots, each one holding about 500 lbs. of glass. The gas was introduced at both ends of the furnace through a pipe, air being admitted by another pipe side by side with the gas, and the supply of both being regulated by taps.

The experienced eye of M. Bontemps detected at once the insufficiency of the heat for the process of glass-making, and he was not surprised to hear from M. Frickentscher

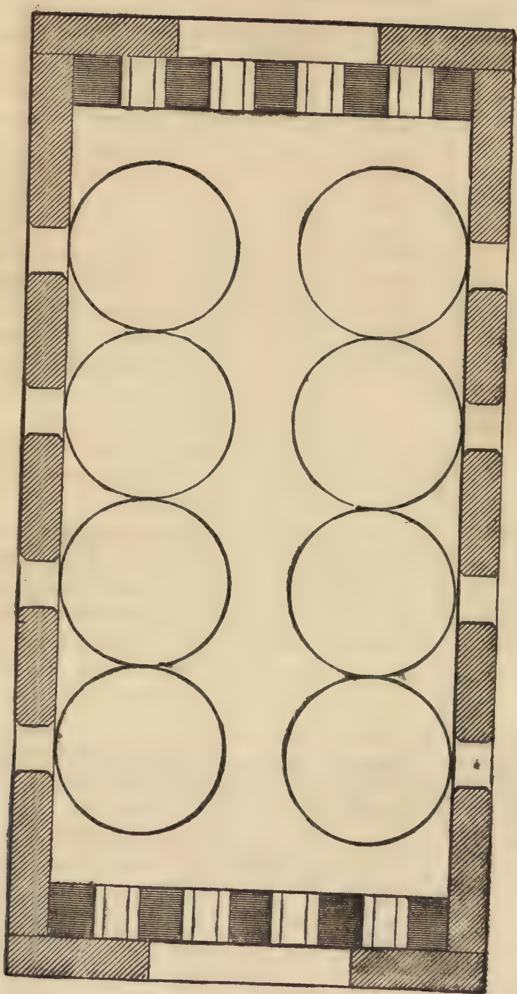


Fig. 2.

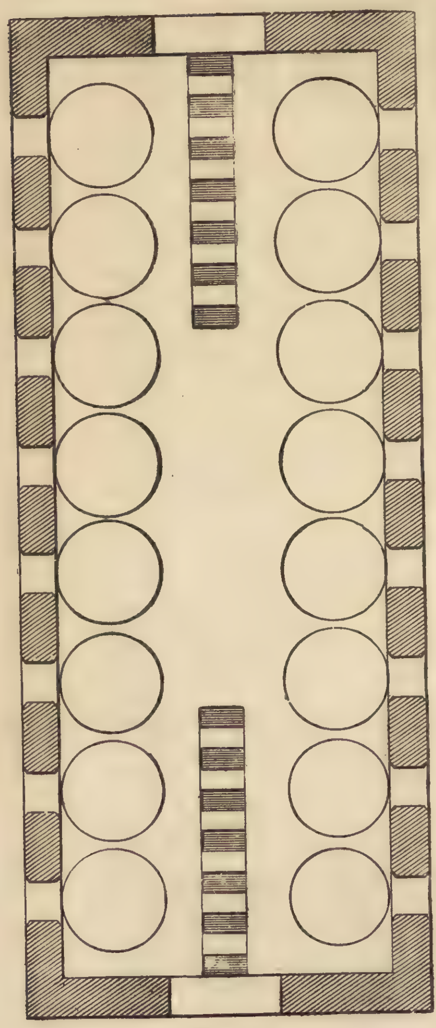


FIG. 3.

that, in spite of a mixture containing a large proportion of alkali, the melting occupied forty-five hours. The furnace, however, of M. Frickentscher is of great interest as the precursor of the far more elaborate and successful invention associated with the name of Siemens.

The novelty of the Siemens system consists in taking up the waste heat from the furnace in large chambers filled with open brickwork, and in making use of the heat thus saved in raising to a high temperature the elements of combustion. In order to carry out successfully the working of this process, the fuel is placed, as in the process of M. Frickentscher, not in the furnace itself, but in large

receptacles, called producers, at some little distance from it. Like the coal furnace, the regenerative gas furnace used in the manufacture of crown and sheet glass is a rectangular chamber with an arched roof. It varies from eight to twelve feet in width, and from ten to forty feet in length, the dimensions being dependent on the size and number of the pots which it has to contain. Although the gas flame is able to travel so long a distance that a furnace may hold twenty or more pots, it is not found advisable in practice to have so large a number.

The top or crown of the furnace is composed of bricks of a special kind. When the regenerative system was

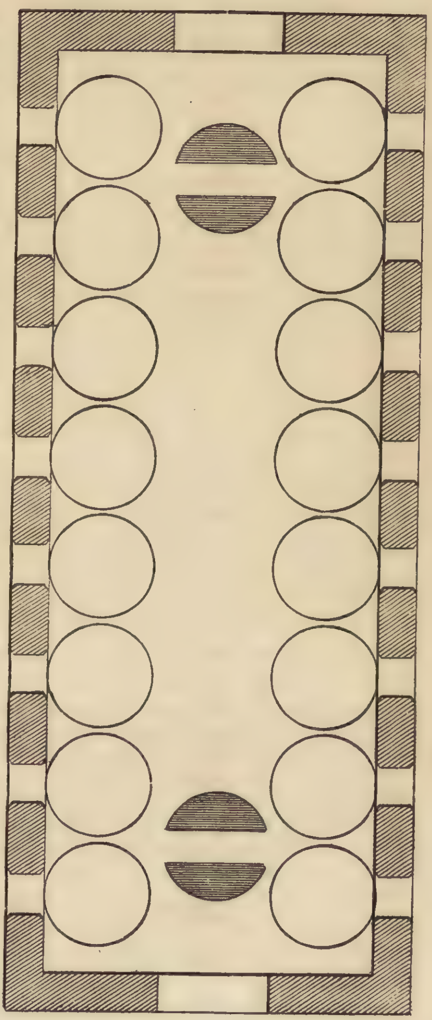


FIG. 4.

first applied to the manufacture of window-glass, it was found that the crowns made of fire-clay were affected by the gas flame in the course of a few weeks to such an extent that the semi-fused clay dropped into the pots, and seriously injured the quality of the glass. This formidable difficulty, which threatened the success of the new system, was overcome by substituting for the clay crown one composed of bricks which contained nothing but pure silica. A crown made of these bricks will last for years without any perceptible wear and tear, and is absolutely infusible so long as it is kept from contact with alkaline or other substances which would act as a flux.

The floor or bed of the furnace, technically called the siege, is in some works made up of large bricks of fire-clay, in others of blocks of sandstone. On the bed the pots are placed in two parallel rows, as in a coal furnace, and similarly situated with respect to one another.

The plan adopted by Dr. Siemens in the first instance was to supply the gas and air at one end of the siege through five apertures (*vide* fig. 2), three giving passage to gas, and two to air. The waste flame passed away at the other end through five similar apertures.

Subsequently he introduced two modifications of the original arrangements. In one the apertures, or ports as they are called, were placed between the pots, the length of the ports being parallel to the ends of the siege, and the number being increased to seven (*vide* fig. 3). In the second modification, one port for the gas and one for the air were placed together near one end of the furnace and, as in the first modification, between the rows of pots, with similar openings in a corresponding position near the other end (*vide* fig. 4).

The regenerative portion of the apparatus consists of two pairs of chambers situated under, or partly under, or in some cases outside the bed of the furnace, each chamber containing a mass of brickwork so arranged as to form a large aggregate surface with intricate zigzag passages.

To give an idea of the system of working, we must suppose that one pair of chambers has been heated to a high temperature. The gas from the producers passing through one of these chambers, and a current of air through the other, meet on or just before entering the furnace, and there unite. Both gas and air have been brought up to a very high temperature by their passage through the heated chambers, and ignite readily on meeting at the entrance to the furnace. The waste flame passes away into the second pair of chambers, and is there taken up. After a time the gas and air have absorbed a considerable portion of the heat of the two chambers through which they passed separately into the furnace, and during the same period the waste flame has raised the second pair to a high degree of heat. By a very simple arrangement the action is now reversed. The gas and air pass through the second pair of chambers, each through its own chamber, and, as before, enter the furnace at a high temperature, while the waste flame passes away through the first pair, which are now comparatively cool, and, by reheating them, prepares them for again giving up their heat when their turn comes. The reversing action, by means of which the gas and air and the waste flame pass alternately through each pair of chambers, takes place generally about every half hour.

The requisite degree of heat in the Siemens furnace cannot be obtained unless both gas and air enter it at a very high temperature. It has been proved by actual experiment that, if the gas only is heated and cold air is admitted, the temperature of the furnace will soon be lowered to such a degree that the process of melting cannot go on.

The admission of gas and air to the furnace is regulated by valves, and considerable judgment is required in the management of these two elements of combustion, the heat attainable being so intense that a slight error may endanger the safety of the whole of the pots. I remember that on one occasion one of the pots having given way, a piece fell from its side against the wall of the furnace, and so soft

was the latter from the intense heat, that the impression of the pot falling against it was as distinct as if it had fallen upon wax.

The producer in which the gas is generated is "a cubical brick chamber, about 8 feet diameter, one side of which is cut off in a slanting direction. Fuel descends on this inclined plane to the grate at the bottom, where combustion takes place. The result of this combustion is carbonic acid at a high degree of temperature. The carbonic acid as it is formed near the grate encounters a further layer of fuel descending from above, which is also incandescent, but which cannot be consumed on the same terms because there is no longer any free oxygen present. The first result of combustion being carbonic acid, a compound of one atom of carbon and two of oxygen, in passing through subsequent layers of fuel is broken up, and a second molecule of carbon is added to the first, thereby producing carbonic oxide, which is a combustible gas. But coal is not simply carbon; it consists also of volatile matters, hydrocarbons, water, and the constituents of ammonia; and the hot carbonic oxide, in passing through a further thickness of the fuel which contains these gaseous constituents, acts upon them in the same manner as heat does upon the coal in a gas retort. This action absorbs a portion of the free heat in the carbonic oxide, and the result is a gas consisting of carbonic oxide, hydrogen, hydrocarbons, aqueous vapour, and nitrogen, which latter, being a constituent of atmospheric air, necessarily passes with it through the fuel, and dilutes the combustible gas produced to the extent of about 50 per cent. of the total volume."[1]

The whole of the fuel except the inorganic portions is converted into gas, there being no reason for separating the illuminating from the non-illuminating products. Thus a very much larger amount of gas is produced from a given quantity of coal than when, as in making gas for illuminat-

[1] From a pamphlet on the "Regenerative Process," by Dr. C. W. Siemens.

ing purposes, a considerable residue is left behind in the form of coke.

The advantages gained by the use of the Siemens furnace are economy of fuel, cleanliness, and the power of regulating with greater nicety than in a coal furnace the increase and decrease of the heat during the various stages.

With regard to the saving of fuel, much depends on the change which the new system can effect in the quality of the coal employed. Where, as for instance in the manufacture of flint glass, large coal is ordinarily used and small coal or slack can, under the Siemens system, be substituted for it, the saving of fuel is very considerable. In processes in which an inferior description of coal is already in use, the margin for economy is very much smaller. Whatever question, however, may be raised as to the comparative cheapness of the process, its cleanliness is undeniable, and for glass made in open pots this is a matter of no small moment. In Belgium the method of working is such that the glass suffers but little in colour from exposure to the smoke of a coal furnace; but in England, especially where non-bituminous coal is used, the amount of coal-dust carried into the pots is considerable, and the system of Dr. Siemens is proportionately beneficial.

The power of regulating the heat of the furnace is felt especially during the period of "working," that is, of gathering the melted glass from the pots. The glass can be kept throughout at its proper state of consistency with more uniformity than in a coal furnace. On the other hand, the passage of gas through the furnace during the period of "gathering" has a tendency to disturb the "metal," and the experience of twenty years is that sheet glass made in a Siemens furnace is more "bliby," that is, has more bubbles in it than were observable under the old régime.

That portion of the manufacture of crown and sheet glass in which the furnace and pots are concerned consists of two distinct operations, viz., the conversion of the raw materials into glass, and the withdrawal of the glass

from the pots in which it has been melted. These operations are performed alternately, and together they constitute what is technically called a "journey," a term derived from the French word *journée*, a day. Formerly, when the pots were very small, the two operations could be completed in twenty-four hours. In England a journey now occupies considerably more than this period, and, owing to the intervention of Sunday, not more than four journeys can be accomplished in a week. On the Continent, where Sunday presents no obstacle, and where the method of working limits the time to be given to cooling or settling the glass, twenty or twenty-two journeys per month are the rule.

Let us suppose that a journey has just been concluded, and that the melted glass has been withdrawn from the pots, a few inches of metal only remaining in each. The "founder," as he is called, with his staff of assistants or "crew," now takes charge of the furnace. The first operation is to heat up the pots thoroughly, before filling them. This occupies from two to four hours, and on it depends in a great measure the success of the subsequent melting or found. M. Bontemps says: "I cannot urge too strongly the importance of attaining as high a degree of heat as possible before putting in the materials, for if they are put in before the siege and the bottoms of the pots have become hot enough, a bad result will follow—the mixture will melt from the top only, the lower part not being sufficiently heated, and whatever efforts the founder may make subsequently, his found will be prolonged, and his glass will be seedy. It is better, therefore, to devote an extra half-hour, or even hour, to warming up, in order that the furnace may be at a proper temperature."

When the pots are apparently ready to receive the mixture, it is thrown in by means of a shovel, until it has filled the pot all round nearly up to the brim, and rises in the centre, in the shape of a cone or sugar-loaf, about eight or ten inches above the pot.

To quote again from M. Bontemps' work: "If the furnace and pots have been brought to a proper degree of heat, there is a gradual fusion of that portion of the mixture which is in contact with the pot, rather than towards the apex of the mass, for the material is by no means a conductor of heat, and the whole filling goes down retaining its original form. This is called a sugar-loaf melting, and gives promise of a successful termination. The melted glass extends itself gradually round the inside of the pot, but there remains still in the centre a small lump, fused only on the surface. At length this sinks to the level of the rest, and the centre portion is melted also. If, on the contrary, the bottoms of the pots are not sufficiently hot, if the furnace has not been properly attended to, if the full heat of the flame is not developed until it is half-way up the pot, in such case the lower portion of the filling is not melted; it is only on the surface that the fire acts, and principally by radiation; the melted cone sinks down, the glass melts "flat," and the centre and lower parts of the filling are melted only by contact with the upper part. The found is prolonged, the glass is badly fined, and seedy, for the seed has not the power to collect itself into bubbles and reach the surface of the pot."

The second filling is generally added within an hour or so after the disappearance of the lump which forms the last remnant of the gradually diminished cone. Some manufacturers, however, prefer to wait for the complete fusion of the first filling before adding a second. In this case it is necessary to take care that no undecomposed sulphate remains on the surface, otherwise the second filling falls on the undecomposed alkali, and a number of semi-vitrified grains are formed which cannot afterwards be got rid of, and which make their appearance in the glass. The former method is generally preferred as the safer of the two. The third filling follows pretty much the same course as the preceding one, and is much smaller,

little being required to complete the quantity of melted glass which the pot will hold. To facilitate the fusion and to promote the "boil" of the metal, some manufacturers make use of a lump of arsenic thrown into the pot shortly before the glass has been fined. A stick of green wood, or a potato, pushed down to the bottom of the pot answers the same purpose.

When the fining process is completed, the founder hands over his charge to the furnace-keeper, whose business it is to settle or cool back the metal to a state fit for the gatherer, and to skim off the impurities or scum on the surface. On the Continent, where, as I have already stated, the same furnace is used for melting and blowing sheet glass, and where it has consequently to be kept hot enough to suit the blower, the settling is very short, not more than two and a-half or three hours. In England, where there is a separate blowing furnace, the glass can be cooled back for such a period as will be most favourable to its quality. The pots being full of melted glass, we have now to consider the processes which follow. Crown glass, as the older of the two in this country, must first claim our attention. Upon the surface of the melted glass is a ring of fire-clay, which, when the materials were thrown in, lay at the bottom of the pot, and after the completion of the melting found its way upwards. This ring is of great service, for, floating in the centre of the pot, it prevents the exterior surface of the metal, which becomes stiff and stringy during the long period of working, from mingling with the interior or hotter surface, which thus remains throughout of a suitable consistency. The labour also of the skimmer, whose duty it is to clear the surface of the metal from any scum or dirt that may collect upon it, is considerably diminished by the ring, which, limiting the space from which the glass is drawn, limits also the space which it is necessary to cleanse, and any bubbles or impurities in the glass have a tendency to attach themselves to the ring.

The metal having been brought, by the gradual cooling of the furnace, from a state of complete fluidity to a consistence capable of being worked, the gatherer dips the end of his pipe or hollow rod of iron, into the pot inside the ring; and twirling it round its axis to equalize the thickness of the gathering, he collects upon the end, or nose, as it is technically called, a pear-shaped lump of glass. Resting his pipe upon a stand or horse, he turns it gently round, and allows the surface of the lump to cool, to fit it for a second gathering. The lump completed, the gatherer, having cooled his pipe by the aid of a trough of water, that he may handle it at any point, proceeds to roll the glass upon a metallic table called a marver, for which may be substituted a block of wood hollowed out to the required form, or a similarly shaped hollow case of metal; upon this table or bed the glass assumes a conical form, the apex of the cone forming the "bullion point." A boy now blows down the pipe while it is still being turned by the gatherer, and expands the glass into a small globe. Having been heated, it is blown again and assumes the shape of a Florence flask. Again heated it is now expanded by the blower into a large globe. During this expansion, it is important to keep the bullion point exactly in the position which it previously occupied, in a line with the axis of the pipe. To effect this, the blower formerly rested his pipe upon an iron support, and while he blew down the pipe and turned it round at the same time, a boy held against the bullion point a piece of iron terminating in a small cup. At the present time the boy is dispensed with, and the bullion point is fixed upon a stand. Again presented to the fire, by the peculiar manipulation of the workman and the peculiar direction of the flame upon it, the front of the globe is flattened, the possibility of the globe collapsing during this operation being prevented by its rapid revolution round its axis. The piece now resembles somewhat in shape an enormous decanter, with a very flat bottom and a very short neck. The bullion point is still

to be seen in the centre of the flat bottom, and its use now becomes manifest. The pipe is laid horizontally upon an iron rest, and a man approaches having in his hand a large rod of iron called a ponty, tipped with a lump of molten glass. Pressing this lump upon an iron point, so as to give it the form of a little cup, he fits it, when thus shaped, on to the bullion point, to which it soon becomes firmly attached. The lump thus formed is called the bull's eye, or bullion of the developed plate. The incision of a piece of cold iron in the glass round the nose of the pipe, and a smart blow, soon detach the pipe, which here takes leave of the piece, and after having lain idle a few minutes, till the glass adhering to it has cracked off, is warmed and carried back to the pot to repeat its course.

The end of the piece which was next the now detached pipe, is called the nose, and gives its name to the furnace or nose-hole where this nose is, on account of its thickness, heated almost to melting, with a view to the coming operation. The glass undergoes this in the hands of a man, who, with a veil before his face, stands in front of a huge circle of flame, into which he thrusts his piece rapidly, meanwhile revolving his ponty. The action of heat and centrifugal force combined is soon visible. The nose of the piece expands, the parts round cannot resist the tendency; the opening grows larger and larger, for a moment is caught a glimpse of a circle with a double rim; the next moment, before the eyes of the spectator, is whirling a thin transparent circular plate of glass, which but a few minutes before was lying in the glass-pot, an undistinguishable portion of the molten mass. Still whirling, the table, as it is now called, is carried off, laid flat upon a support called a whimsey, detached by shears from the ponty, lifted into the annealing kiln upon a fork, and piled upon its edge against the preceding table. The weight of so many tables pressing one against another would cause the hindermost to bend; but this is prevented by the inter-

vention of iron frames or drossers, which divide the tables into sets, the first drosser leaning against the wall of the kiln, the second against the first, and so on, and thus rendering each set of tables independent of those behind it for support. As the bull's-eye or centre lump which the ponty has left behind it, keeps each table from close contact with its neighbours, the air passes freely between them, and the annealing is accomplished with tolerable rapidity, varying from twenty-four to forty-eight hours, according to the number of tables in the kiln. From the kiln the tables are conveyed to the warehouse, having passed, since their first exit from the pot, through the hands of ten distinct workmen.

In the warehouse the tables are laid upon a "nest," or cushion, and are divided by the diamond of the splitter into two unequal parts, the larger half containing the "bull's-eye." The diameter of the table is measured on the nest, the usual size being now about 54 inches, and weighing 13 lbs. Tables have been made as wide as 70 inches, but the difficulty of manipulation and the uncertainty of the result render such sizes too costly to be general.

The splitter carefully examines each table before splitting it, and turns it round till he has brought it into the position in which he may split it to the best advantage, ascertaining at the same time its quality.

The variations in quality depend on the presence or absence, number, and extent of those defects to which, even in the best regulated manufactories, glass is unavoidably liable. Perhaps the glass has been badly melted, and is seedy, full (that is) of little vesicles, to which the rotary motion has given a circular shape. Or the gatherer may have enclosed air within his "metal," and a gatherer's blister is the result; or a pipe blister or pipe scales, or dust from the pipe-nose, or dust from the bottoming hole, or dust from the nose hole, or dust from the flashing furnace, or bad bullions or scratches, or music lines, may disfigure the table, or the glass may be crizzled, or curved,

or bent, or hard, or smoky, or small and light—defects, to explain which would be a long and dreary task. No wonder that tables of the best quality are few and far between, in some manufactories a forlorn hope never to be realized.

Independently, however, of these defects, there are certain other disadvantages under which even a faultless table of crown glass must unavoidably labour. The cutting of a circle into rectangular sheets must, necessarily, be attended with waste, while the bull's-eye confines those sheets to comparatively small sizes. Uniformity of thickness, also, except by the most skilful manipulation, is difficult of attainment.

On the other hand, extreme brilliancy of surface, ascribed by some to the effect of the flashing furnace, is a characteristic of this glass, but this merit has not enabled it of late years to maintain its position against its rival, sheet glass, increased dimensions being, for ordinary purposes, of much more consequence than mere beauty of appearance.

Sheet glass, like crown, has its beginning in a lump of "metal" collected on the end of the gatherer's pipe. This lump is placed on a block of wood, so hollowed out as to allow the glass to be expanded by the blower to the diameter ultimately required. The block during this operation is sprinkled with water to prevent the wood from being burnt, and from scratching the glass. In some works a hollow metallic block is substituted for the wooden one, the upper part being made of the required shape. Charcoal is used to protect the glass from scratches, and the block is kept cool by water passing through it. From the block the glass is carried to the blowing furnace, or back to the melting furnace if used also for blowing, and is heated in one of the apertures, a separate aperture being allotted to each blower. In front of the furnace, and corresponding to each opening, is a stage or frame of wood, erected over a large pit or well about 10 feet deep,

and these parallel stages are sufficiently apart to enable each blower to swing his pipe to and fro in a vertical plane, that the glass may run freely out, as the phrase is, to the required length. When the glass has been sufficiently heated in the blowing furnace, it is brought out and swung round in a vertical plane, and also backwards and forwards, and the blower at the same time, by blowing down the pipe, constantly keeps the lengthening cylinder full of air. Uniformity of substance and of diameter is chiefly secured by the skill of the workman, who, when he finds the metal running out too freely, holds the cylinder vertically above his head, still keeping it well filled with air. These operations are continued until the cylinder has reached the length required. The diameter of the cylinder was determined by the block, and remains the same throughout.

The next stage of the process is opening the end of the cylinder. The thinner kinds of glass are all opened by submitting the end of the cylinder to the fire, and at the same time forcing in air through the pipe and stopping up its aperture. The air is expanded by the heat of the fire and bursts open the cylinder at the end, this being the hottest and most yielding part. The aperture thus made is widened out to the diameter of the cylinder, by subsequently turning the cylinder to and fro with the opening downwards.

The thicker kinds are opened by attaching a lump of hot glass to the end of the cylinder, which thus becomes the hottest and weakest part; and the air forced in by the blower as before bursts it open. The opening is then enlarged by cutting it round with scissors.

If opened in the furnace, as in the first case, the ends of the thicker cylinders would be so thinned out that a considerable portion would be wasted.

In England the blowing of very large and heavy cylinders is assisted by the use of an apparatus called an "iron man." It consists of an iron rail about twelve feet

long, fixed to the front of the blowing furnace over the swing-hole, and carrying a pair of wheels. Connected with these wheels is an iron rod, which hangs down, and can be swung backwards and forwards, and by the aid of the wheels can also be moved to and from the furnace. The pipe of the blower, being attached to the vertical rod, can, with its cylinder, be moved in the same manner as the rod, and can be swung to and fro and taken to or from the furnace, without having to be supported by the blower. The use of this machine has been discontinued in Belgium, even by its inventor.

The cylinder, after it has been opened, is laid on a wooden rest or "chevalet," and is easily detached from the pipe by the application of a piece of cold iron, or steel, to the neck of the glass near the pipe-nose. The neck being hot suddenly contracts externally, and breaks away from the cylinder. There still remains the cap, or end, which is easily taken off by wrapping round the end of the cylinder a thread of hot glass, removing the thread, and applying a piece of cold iron to any point which the thread covered.

The finished cylinder is split open by a diamond which, attached to a long handle, and guided by a wooden rule, is drawn along the inside length of the cylinder. If there are any large defects it is desirable to split as near as possible to one or more of them, so as to bring them to the edges of the subsequent plate of glass, and thus to place them in the position least injurious to it.

The use of the diamond in splitting plain surfaces of glass dates from the sixteenth century ; but its application to the splitting of cylinders, which had not undergone the process of annealing, was introduced not more than fifty years ago by M. Claudet. On the Continent the cylinders are, for the most part, split with a red-hot iron, each blower splitting his own pieces.

The cylinder is now ready for the flattener, who, having prepared it by a preliminary warming in the flue by which

it is introduced into his furnace passes it by means of a croppie, or iron instrument, on to the flattening-stone, from the slight irregularities of whose surface it is protected by a lagre or sheet of glass laid upon the stone. Upon this lagre the cylinder, lying with the split uppermost, is soon opened by the flame passing over it, and falls back into a wavy sheet. The flattener now applies another instrument, a polissoir, or rod of iron, furnished at the end with a block of wood, and rubs down the waviness into a flat surface, often, upon a refractory piece, using considerable force. Some cylinders are so distorted in the blowing that no rubbing can flatten them, but all, good, bad, and indifferent, pass through the same treatment. The flattening stone is now moved on wheels to a cooler portion of the furnace, and, by the aid of the flattening fork, delivers its sheet to another stone, called the cooling-stone. From this it is again lifted, when sufficiently stiff, and is placed either flat, or on its edge, in a movable receptacle, which, when it has its proper complement of sheets, is replaced by another. Thus the operations of flattening and annealing go on continuously. In the process invented by M. Bievez, the flattened sheets are passed through the annealing chamber one at a time. A single sheet will cool very rapidly, and passing through a gradually decreasing temperature, at the end of about half an hour after its entrance into the flattening kiln it emerges thoroughly annealed.

From the flattening furnace the sheets, when annealed, are carried to the warehouse, to undergo examination. In some works, sheets specially selected, as having very minute or only superficial defects, are ground and polished by machinery specially adapted to the purpose, and, after having been thus treated, are known by the name of patent plate.

Sheet glass, blown by a less complex process than crown, is liable, in the glass-house, to a less number of defects, but the after process of flattening often makes up

the deficiency, and the manner in which a sheet, spared by one process, is disfigured by another, is sometimes curiously provoking. Standing before the table of the assorter, your eye lights upon a piece which, blown under an evil star, has imbibed in the glass-house every possible defect. The founder, skimmer, gatherer, and blower have all stamped their brand upon it. It is seedy—the vesicles, which were in the crown tables rounded by the rotary motion of the piece, here elongated by the extension of the cylinder; it is stony, disfigured with stony droppings from the furnace—stringy, thin threads of glass meandering over its surface; ambitty, covered with stony speckles, symptoms of incipient devitrification; conspicuous with gatherer's blisters, and blisters from the pipe—badly gathered—badly blown—thin here, thick there, and grooved with a row of scratches; and on this abortion the flattener chances to have exerted his most exquisite skill; it has passed through his hands unscathed, flat as a polished mirror, yet, from its previous defects, entirely worthless. Next comes before you a piece whose beginning was miraculous; no seed, no blisters; it prospered under the hands of the gatherer and blower, and left the glass-house a perfect cylinder. But the croppie of the flattener marked it, the fire scalded it, dust fell upon the lagre and dirtied it, scraps from the edges of the preceding cylinder stayed upon the lagre and stuck to it—the stone scratched it, and the heat of the annealing chamber bent it. Such are the difficulties to which every cylinder is subject. All, however, are not bad, but the good are generally in the minority.

The thickness of sheet glass is computed by the number of ounces to the square foot—15, 21, 32, 36, and 42 ounces represent the standard thicknesses. The standard qualities are best, seconds, thirds, and fourths. The average size of 15 and 21 oz. glass is 48 inches by 34 or 36 inches.

Sheets have been made without the assistance of the

"iron man" as large as 82 in. by 42 in. and 75 in. by 50 in. Cylinders have been exhibited of the enormous dimensions of 158 in. long and 26 in. circumference, and 70 in. long and 60 in. circumference.

The size which sheet glass can thus reach is obviously a great advantage, and adapts it to many purposes from which the limited dimensions of crown are excluded. But it is devoid of that brilliancy of surface for which crown glass is so remarkable. It is subject also to undulations on the surface, the precise origin of which it is difficult to explain. Mr. Shaw, in his admirable lecture on the glass manufacture as illustrated in the great Exhibition of 1851, speaking of this defect says: "When the divided cylinder is softened by heat, and either allowed to flatten by its own weight or flattened by the workman, the concave interior of the cylinder has to expand, and the convex exterior to contract, as the curved surface becomes plane. Were this contraction and expansion to take place uniformly throughout the glass, the undulation in question would not occur, but, since one part invariably yields more readily than another, perfect flatness cannot be attained."

It is, however, more probable that this undulation is produced in the operation of blowing, and is due to the double movement of the particles of glass which accompanies the formation of every cylinder, the one movement being parallel to the axis of the cylinder, and the other in planes at right angles to that axis.

English crown and sheet glass may be said to contain, in round numbers, 72 per cent. of silica, 13 per cent. of soda, 13 per cent. of lime, and 2 per cent. of alumina and oxide of iron. Foreign sheet glass contains generally rather more silica, and rather less soda. On comparing the proportions of the materials in the mixture with the composition of the glass produced, there does not appear to be more than a very slight volatilization of alkali (exclusive of the chloride of sodium present) during the intense heat to which it is subjected.

With regard to the important question of the existence of colour in glass, to which no colour is intended to be given, it may fairly be assumed that it arises mainly from impurities existing in the materials, or introduced during the processes of melting and working. The character of the colour which they impart probably depends on the oxidation or deoxidation which they undergo. As Mr. Pellatt remarked at a meeting of the Society of Arts in 1856, oxide of manganese is used to correct the green tint caused by the presence of protoxide of iron, the effect being to change the green to a brownish-yellow colour. "This," he said, "was not obtained by the pink colour of the manganese being antagonistic to the green, and thus subduing it, but by the iron taking another charge of oxygen from the manganese, and so becoming the peroxide of iron, the colour of which was a reddish-yellow, whilst the protoxide was green. That the colour of oxide of manganese was due to the oxygen was readily proved by thrusting a green stick into a pot of glass made with manganese, the colour of which was purple. The purple would shortly disappear, and a green would take its place, solely from the abstraction of oxygen. Changes in the colour of glass from exposure to light or heat might be accounted for on the same principle." That a longer or shorter exposure to the sun's rays will probably alter, in more or less degree, the colour of all kinds of window-glass appears to be a fact as to which scientific men are agreed, but as to the cause of the change there is considerable difference of opinion.

Another question of great importance in relation to glass of all kinds, and not least to window-glass, has of late years occupied much attention—namely, how to strengthen or toughen glass, so as to enable it to bear a heavy blow without breaking.

M. de la Bastie succeeded in imparting considerable strength to glass by plunging it, while hot, into a bath of oil or melted fat. The treatment of window-glass by this

method was open to the fatal objection that, after having been thus treated, it could not be cut with a diamond. It was also liable to break suddenly without any apparent cause. Other inventors followed in the steps of M. de la Bastie. Among them was Mr. F. Siemens, the owner of large bottle works in Germany and Bohemia. He conceived the idea of tempering articles of glass by placing them in moulds between cooled surfaces, thus maintaining their shapes intact, and applying force, if necessary, so as to press the molecules of glass firmly together. By this means glass of any shape could be tempered, but Mr. Siemens soon found that glass so prepared was also liable to sudden breakage. He attributed this defect to the fact that, while the corners of the glass presented three, and the edges two cooling surfaces, the flat portion of the plate had only one, and that to the consequent want of uniformity in the rate of cooling the sudden breakages were due. To overcome this defect, he modified the process so as to limit the cooling influence of his apparatus to two surfaces of the glass under treatment, and by this means obtained homogeneous glass.

Plates thus treated will bear the action of the sand blast, but they cannot be cut with a diamond without risk of breakage. This is a difficulty which has hitherto baffled the ingenuity of all producers of toughened glass, but Mr. Siemens hopes to overcome it.

In describing the manufacture of crown and sheet glass, I pointed out that there were two distinct operations connected with the furnace, namely, the conversion of the raw material into glass, and the withdrawal of the glass from the pot, these two processes following one another in regular succession. A considerable time is occupied in melting the materials and in bringing the melted glass into a proper state of consistency, during which period the work of the gatherer, and consequently also that of the blower, are suspended.

To do away with this interval, and to melt and blow continuously, without adding to the cost or injuring the quality of the glass, is a problem by no means easy of solution.

M. Bontemps, in the "Guide du Verrier," from which I have already quoted, describes the plan adopted by M. Chamblant, who made use of a large curved pipe (fig. 5), one end of which dipped into the pot while the other fitted to the aperture of the furnace. Some of the pots were used for melting, others for working. Into the former the materials were introduced through the pipe, outside which the glass as it formed rose in the pot. Thence it

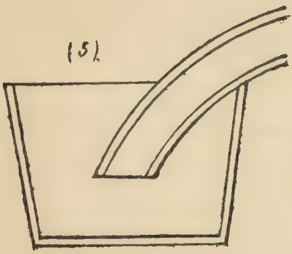


FIG. 5.

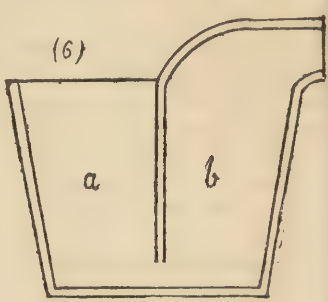


FIG. 6.

was transferred by means of a ladle to the working pot, not through the pipe, but outside it, and the refined portion only of the glass made its way into the pipe, and was withdrawn by the gatherer. By this method the introduction of fresh material into the melting-pot, and the transfer of the melted glass to and its withdrawal from the working-pot could be carried on continuously.

M. Bontemps refers also to a pot divided into two compartments (fig. 6), one of which was open, while the other was covered with a hood or bonnet. The materials were thrown into the open part (a), and as the dividing

wall did not extend quite to the bottom of the pot, a space was left through which the melted glass passed into the working compartment (*b*). Both these methods appear to have had only partial success in attaining the object in view.

In Dr. C. W. Siemens' specification of 25th May, 1870, a pot is described similar in principle to the foregoing, but having three compartments instead of two, the intermediate one being for the purpose of making the process of melting more complete. This pot, the invention of Mr. F. Siemens, having (as Dr. Siemens informs me) been tested sufficiently to show that glass could be melted and blown continuously, and of a suitable quality, was abandoned in favour of the continuous tank-furnace, the first plan of which appeared in the same specification. To quote the words there used, "The tank is divided in its length into three compartments by means of transverse partitions or bridges, provided with air-passages in communication with vertical air-shafts for effecting a circulation of cold air through the same. Into the hindmost of the compartments the crude materials are introduced, and as they melt they pass through apertures at the bottom of the first bridge into vertical channels formed in the same, in which the melted glass rises and flows over the bridge into the middle compartment, where the operation of melting is completed. Lastly, the glass flows from this compartment through apertures in the bottom of the second partition into the front or working compartment." From this it is withdrawn by the pipe of the gatherer in the ordinary way. No separate furnace for blowing is required, as the apertures through which the glass is gathered serve as blowing-holes, and the working compartment is kept at the temperature required by the blower.

In a subsequent specification, dated 21st November, 1872, the fixed partitions are replaced by "bars or girders of fire-clay, or other refractory material," which float on the surface of the molten matter, and are "placed therein

transversely, at intervals, so that they form floating bridges dividing the upper stratum of the molten matter into compartments. The imperfectly melted or impure material is thus kept at the supply-end of the tank. and only the more thoroughly melted and purer matter is permitted to flow towards the working-out end by passing down under these floating bridges."

More recently bridges, whether fixed or floating, have been dispensed with, as being a somewhat weak part of the system. To quote from the information which Dr. Siemens has kindly placed at my disposal:—"The furnace, as now constructed, consists of a long tank about four feet deep, with a semicircular end. It is heated by means of gas and regenerators, the flame ports being arranged on both sides of its parallel faces. The working holes are at the semicircular end, the charging holes being situated at the opposite end, which is generally rectangular. The tank is constructed partly over, and is supported by, the regenerative chambers, which are built in pairs at each side of the structure. The other parts of the furnace, including its producers, are built in the usual manner of regenerative gas furnaces. The tank is not furnished with any division wall or bridge, but forms a huge long basin, heated internally from above over its entire surface, except at the end where the metal is gathered, which is kept sufficiently hot by radiation from the flame. Floating pot-clay vessels are used, into which the glass enters at a considerable depth below the surface of the metal in the tank, and is therein refined previous to being withdrawn by the gatherer. The dimensions of a floating vessel vary according to the quantity of metal to be withdrawn in a given time, but it always has either three compartments or two compartments and a floating ring, the latter being the equivalent of the third compartment. The first compartment is the inlet for glass, the second is the refining one, and the third is that from which the gatherers withdraw the glass. The division

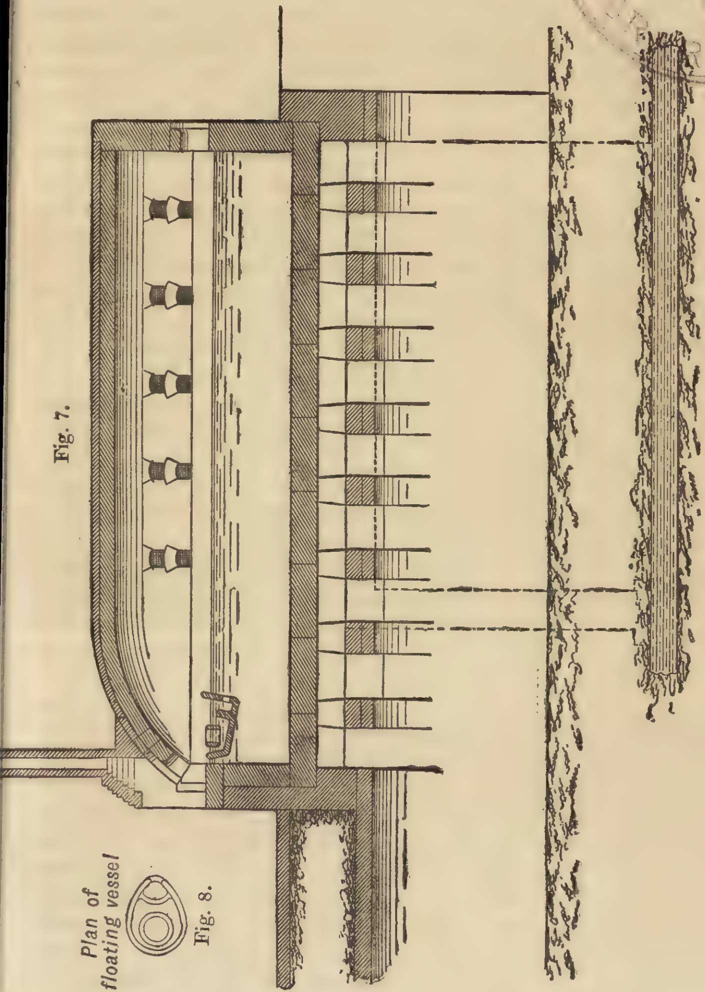


Fig. 7.

Plan of floating vessel

Fig. 8.

between the first and second compartments rises from the bottom of the vessel, so as to form a dam to prevent the back-flow of the refined glass into the tank, but the second and third compartments communicate with each other at the bottom, so that glass shall be gathered only from the most dense or, in other words, the best stock in the floating vessel. For the production of window-glass of high quality, vessels with loose rings are preferred, as the rings may from time to time be removed and exposed to the heat of the furnace in order to clear them of adhering matter, formed by the decomposition of their interior surfaces, which otherwise would deteriorate the glass."

Annexed is a drawing of a longitudinal section of the tank-furnace with its floating vessel, and also a plan of the latter. (*Vide* figs. 7 and 8.) I purposely abstain from making any comparison between the results hitherto obtained from pots and tank-furnaces. The latter are of recent date; they are, as is clear from the foregoing description of them, in process of development, and up to the present time they have been adopted by a few only of the manufacturers of window glass, by far the greater number adhering to the old system. But although the continuous process may not as yet have realized all the advantages claimed for it by its inventors, it has undoubtedly been carried out on so large a scale and with such success, as to have become one of the recognized methods of the manufacture of window glass.

Note.—As that portion of the preceding chapter which relates to the processes of blowing crown and sheet glass will be found to be for the most part identical with what has appeared on the same subject in Spon's "Cyclopædia" and other publications, it may be as well to state that my own and other similar descriptions of the two processes are derived from the same source, namely, from a lecture which I delivered before the Society of Arts in 1856. The description then given was prepared with so much

care that I have confined myself to making such alterations and additions as have been rendered necessary by recent modifications in the methods of manufacture. I may add, that the chapter contains a large amount of matter which does not appear in the lecture.

ON THE MANUFACTURE OF PLATE GLASS.

BY H. GRAHAM HARRIS, ASSOC. MEMB. INST. C.E.

THE term plate glass is applied to that form of glass which is manufactured by pouring or casting the molten "metal" upon a perfectly flat, smooth, iron table, and by passing a smooth parallel iron roller over the mass thus formed, while it is in a plastic state, or in that state of viscosity which glass assumes when it is at a temperature slightly less than that necessary to keep it molten.

There are two descriptions of plate glass, the one technically known as "rough plate," and the other as "polished plate." Rough plate is manufactured in the simple manner above described. Polished plate consists of rough plate, which after casting, has had its surfaces ground, smoothed, and polished.

The process of rolling plate glass may be familiarly compared to that of rolling dough as in the preparation of pastry. In the case of plate glass, however, the table, or "paste-board" is of planed cast iron, and from 30 to 40 feet long by 15 to 20 feet broad, and the roller or "rolling-pin" is of cast iron, of a length equal to the whole width of the table turned parallel, some 2 feet in diameter, and weighing many tons, being moved backwards and forwards over the surface of the glass, by several men hauling upon tackle attached to its ends.

Rough plate, or plate which has only been thus pre-

pared, is dull in appearance, and is hardly even semi-transparent; this latter fault being partly due to the variations of light and shade upon its irregular surfaces, and partly to the change which these surfaces have experienced, by their rapid cooling from contact with the air, and with the metal of the table and of the roller. This rough plate, however, after having its irregular semi-opaque surfaces removed by grinding and polishing, becomes that beautifully brilliant and transparent material which is commonly known as plate glass.

Rough plate is almost entirely used for the purposes of lighting. Polished plate, however, in addition to this, is also used for looking-glasses and mirrors. Sheets of large size are needed, and are usually made, and as the finished thickness is as much as from three-eighths to five-eighths of an inch, it is manifest that large quantities of the materials from which the glass is made must be dealt with at one time. Great purity in the ingredients of which the glass is composed, and great care in the proportioning, mixing, and manipulation of these ingredients, is therefore necessary, as the failure to produce a commercially successful sheet of glass, would, in each separate instance, involve a large loss.

The discovery of the art of making glass is one of the earliest of which mention is made in the history of the world. Pliny speaks of it, and relates how some mariners, lighting their cooking fire on the banks of a stream, rest the pots in which their food is being cooked upon masses of soda, a cargo of which they are carrying. The heat of the fire melting this soda, it mixes with the sand on the river bank, and the sailors are surprised to find after their fires are extinguished, a mass of glass. It is extremely doubtful whether the heat of an open fire would be sufficient to produce glass in this manner, but whatever may have been the origin of the discovery, there are records of the art having been practised by the Sidonians and by the Phœnicians. Upon considering the question it would ap-

pear that, if glass were needed for the purpose for which in this age it is most commonly used, *i.e.*, for that of lighting, its manufacture in sheets by casting, would be one of the earliest adaptations of the discovery. No mention of this occurs, however, until about the year A.D. 422, when St. Jerome speaks of sheets or plates of glass being obtained by casting—the casting-table being a large flat stone. Some hundred years later it is noted that the church of St. Sophia has its windows glazed, the glass used for this having been most probably obtained by casting.

It was not till the year A.D. 1688 that the manufacture was revived, and rendered of any great commercial value. In this year a Frenchman named Thevart, having obtained a patent for his invention, granting him or his licensees a monopoly of the manufacture for thirty years, established works in Paris. These works were subsequently removed to St. Gobain, and here the manufacture of plate glass is still carried on; this manufactory being the largest in the world. For nearly a hundred years after this date plate glass was only to be obtained from France, and it was not until the year 1772 that a "Company of Adventurers" was incorporated under the title of "The Governor and Company" "of the British Plate Glass Manufacturers" for the purpose of manufacturing plate glass in England. The Act under which this company was constituted was entitled "An Act to incorporate certain persons herein "named, and their successors, with proper powers, for the "purpose of establishing one or more glass manufactories "within the Kingdom of Great Britain, for the more effec-"tually supporting and conducting the same upon an im-"proved plan in a peculiar manner, calculated for the "casting of large plate glass." The Act recites how the revenues of the kingdom will, in all probability, benefit largely from the establishment of these manufactories, by the imposition of duties to be paid on all completed glass, and how also it is possible that the mode of manufacture of the glass itself will be greatly improved. In pursuance

of the powers obtained under this Act, the Company procured workmen and machinery from France, and built a manufactory at Ravenhead, near St. Helen's, in Lancashire (fitting it completely in every respect), and commenced the manufacture. These works are still in operation, and as time has passed they have been improved and perfected in every department, so that they are now among the most efficient which are to be found. Other works have been established in various parts of the country, notably at Poplar in London, and at Sutton, near the original works at Ravenhead. In these days, therefore, instead of the greater portion of the plate glass used in this country being imported from France and Belgium, we make sufficient not only to satisfy our own wants, but are able also to supply our neighbours.

The materials of which plate glass is composed, and the chemical changes which those materials undergo, have been so fully and minutely described in the earlier portions of this work (see pages 2 to 11), that it is unnecessary they should be repeated here, but it is only needful to urge, as has already been done, the great necessity there is in this manufacture for extreme care, not only in the selection of these materials in the first instance, but in their proportioning, mixing, and manipulation in all the various stages through which they have to pass.

The sand or silica which forms the basis of all glass must, in the case of plate glass, contain the smallest possible amount of impurity, either organic or metallic. To remove the organic impurities the sand is first thoroughly washed and then calcined or burnt, this latter operation serving also to remove the moisture left in the sand from washing. Iron in the form of oxide of iron is the metallic impurity which exists even in the purest descriptions of sand, the evil effects of this must be neutralized by the admixture of arsenic, or the glass will be imperfect as regards its transparency and also as regards its brilliancy. Finally, before being mixed with the other materials, the sand must be

thoroughly sifted, so that only such portions of it as are of the finest grain shall be used. Sand for the manufacture of plate glass is obtained from France, no deposits of it in this country being sufficiently pure.

The limestone is delivered at the works in large, irregular-shaped pieces, in fact in the same condition as that in which it is obtained at the quarries. These are broken or crushed and ground to an impalpable powder, and then sifted, in order that only such portions as are finely powdered shall be used. The breaking or crushing of the limestone is usually performed in a machine known as a Blake crusher, see fig. 1, which shows a section through the machine.

The Blake crusher is commonly in use wherever it is needed to break or crush refractory materials of large size, such as flint, limestone, emery stone, the "clinker" of cement, &c. &c. It consists of a machine driven either directly by an engine or by a belt upon a pulley, A, the rotary motion given by either of these means being communicated to a shaft, B, running through the machine. This shaft has the central portion of its length not concentric with its centre, but eccentric to it; upon this eccentric portion works the boss of a long-armed lever, technically known as the "pitman," C, the other end of this pitman forming as it were the central pin of a jointed lever, D D; one end of this jointed lever takes its thrust against the framework of the machine, and the other end takes its thrust against the lower end of an inclined jaw, E, which is pivoted at its upper end, and has its face presented to a vertical jaw, F, fixed in the machine. The opposing faces of these jaws are formed of hardened steel or chilled cast-iron, and are serrated. It will be seen that upon motion being given to the shaft its eccentric portion will cause the lower end of the pitman C to rise and fall, and will therefore by means of the jointed lever D D cause the lower end of the inclined jaw, E, to move at right angles to the face of the fixed jaw, F. The material to be crushed being filled into the top of the machine, and allowed to fall into the space between the jaws,

E and F, is crushed by them and passes away at the bottom. The hooked rod H is attached at one end to the lower part

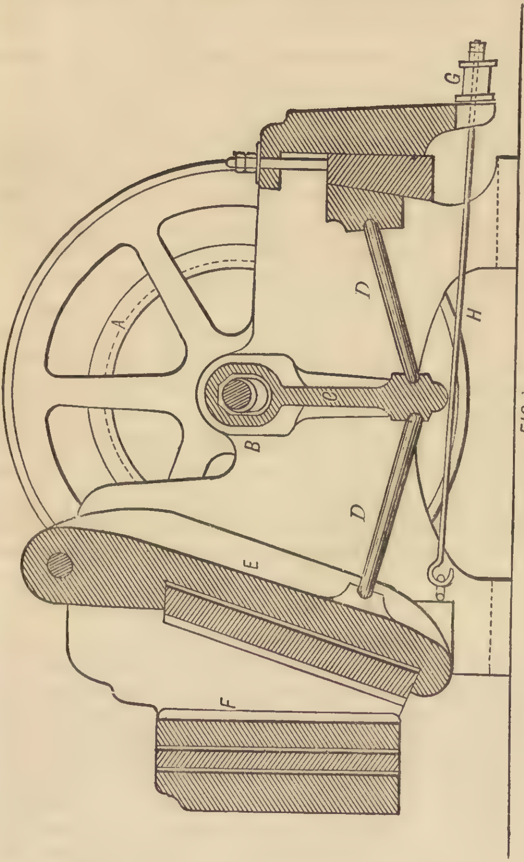


FIG. 1.
"BLAKE" CRUSHER.

of the inclined jaw, E, and at its other end passes through the framework of the machine, and is provided with india-rubber discs, G, which are compressed, as the inclined jaw

moves forward, between a washer secured to the end of the hooked rod and the framework of the machine; the elasticity of the rubber therefore tends to bring the inclined jaw vertical, and therefore to keep its back hard against the one end of the jointed lever, D. Arrangements are made by means of the wedge H so that the lower end of the inclined jaw can be set nearer to or further from the face of the fixed jaw, and thus cause the material to be crushed to a greater or less degree of fineness, before it can pass away from between these jaws.

After passing through a machine of this description, the pieces of limestone are further crushed under a pair of "Edge Runners." This machine consists (see fig. 2), of a vertical revolving shaft, A, at right angles to which are fixed the axes of two discs or rollers, B B, capable of revolving upon their axes, and having their lower edges rolling upon the bottom of a cast-iron pan, C. The material to be crushed is filled into the pan, and rotary motion being imparted to the vertical shaft, A, the rollers, B B, pass round with it, crushing the material between their outer circumferential surface and the floor of the pan as they roll over it. Scrapers are also fixed to the vertical shaft, A, and revolve with it, these scrapers directing the material in the pan under the rollers as they pass round. A portion of the floor of the pan is made as a sieve, and the material when sufficiently crushed under the runners, falls through this sieve and is collected below the pan. From here the material is taken to a hand or machine-worked sieve, and the "tailings," or those portions which will not pass through this sieve, are returned to the edge-runners and are re-ground.

Powdered anthracite coal, which is one of the ingredients used in the manufacture of plate glass, as has already been described, is also prepared by crushing and grinding in edge-runners, and by subsequent sifting, and the "salt cake" (as it is technically called), or sulphate of soda, is likewise pulverized and afterwards sifted.

The principal point to be attended to in this part of the manufacture is, that the various materials which are to be

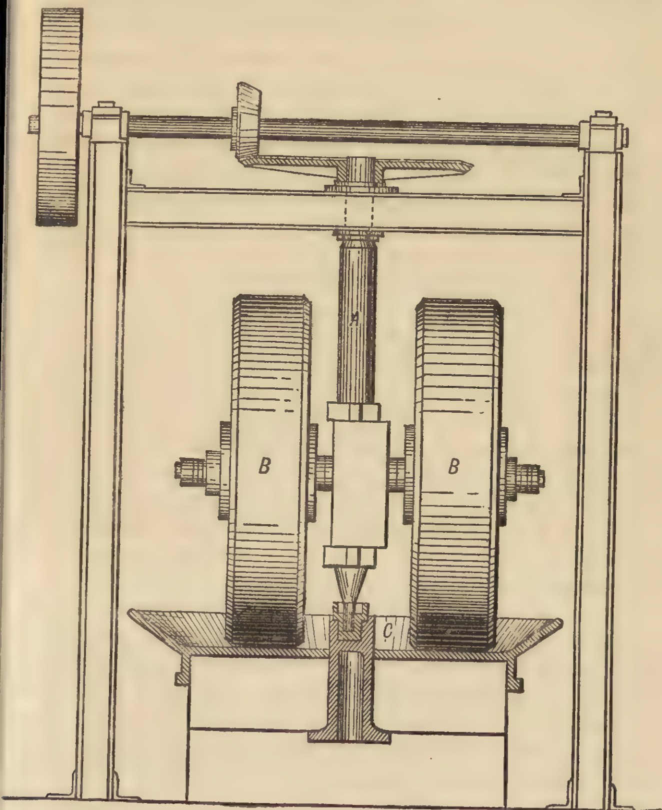


FIG.2.
EDGE RUNNERS.

used shall be in as fine a state of powder as it is possible to obtain, and that they shall be carefully dried, so that the mixing may be of the most complete and intimate

character, and that each separate portion of the material, shall, when the "metal" is complete, find itself in proximity to other portions of material of different descriptions. To insure this intimate mixture, the proper proportion by weight of each of the various ingredients is placed in the pan of another pair of edge-runners, and the "batch," as it is called, is subjected to the action of these runners, and, when sufficiently mixed, is afterwards passed through a succession of sieves. If extreme care such as this is not exercised, it will be found when the metal is reduced in the melting furnace that complete mixture of the materials is not obtained, and the glass will be seedy and blistered. In all meltings, however, a large quantity of old glass or "cullet" is used, partly with the object of utilizing the waste which would otherwise take place from breakages during the manufacture or the sorting and packing, or from other causes, and partly with the object of assisting the melting, as the temperature at which this old glass will melt is less than that required to melt the uncombined materials of which the glass is formed. Only such portions of this cullet, however, as are of the finest quality are employed, and it is not thought necessary to re-grind and mix this with the other materials; the mixing which results from the melting being considered sufficient.

From the mixing room, the "metal," or mixture of materials of which the glass is to be formed, is taken to the casting room or casting hall, in which the furnaces for melting are usually placed. The pots in which the metal is melted, are similar to those already described, in the earlier portions of this work. Of late years, however, it has been found that a modification of the shape originally used, tends to preserve the pot, for a much longer period. Fig. 3 shows a section, through a plate-glass melting-pot as now constructed. It is absolutely necessary that all chances of failure in these pots should be considered, for it may almost be said that upon the careful making and use of these pots in a plate-glass manufactory, does the suc-

cess of that manufactory depend. These pots are of large size, in order that each may contain sufficient molten glass to form a sheet of the largest size, and they weigh in themselves as much as from 7 cwt. to 9 cwt., and will contain as much as one and a half tons of molten glass.

Great importance is attached to their manufacture. The clay of which they are composed must be of the very finest description, that is to say, must be practically in-

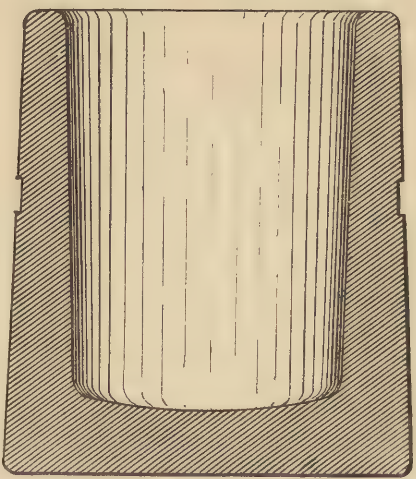


Fig.3.
Section of Plate Glass Melting Pot.

fusible, and must contain the greatest proportions of silica and of alumina. After being quarried it is found advisable to leave it exposed to the weather for some two or three years, turning it over occasionally to mature or ripen. When ready for use it is carefully kneaded, cut, and trodden, and then mixed first in a pug-mill, and afterwards in edge-runners, having as small a quantity of water added to it as will allow of its being easily worked. Great attention is paid to this point, as the whole of the water has to

be evaporated from the clay after the pot is made, and before it can be burnt, and evaporation must not take place too quickly, or the surfaces of the pot will become dry and hard while the interior portions will still be moist, thus unequal contraction will be set up, and cracks and flaws will occur. The great thickness of the sides and bottom of the pots is necessary, in order to give sufficient strength, to enable them to sustain the weight of the molten glass, and therefore a long time is required, after the pot leaves the hands of the potmaker, to slowly evaporate the water, which has been mixed with it in the kneading. The old pots, *i.e.*, those which have already been used or have from any cause failed in being baked or burnt, are broken up, and after having all traces of the glass which may have stuck to them carefully removed, the pieces are crushed and ground to an impalpable powder and sifted, and a certain proportion of this powdered clay is carefully and intimately mixed with the new clay.

Machines for the construction of these pots have been devised, but although the pot when made in these machines, has to all appearance been as good as, or even better than the one made by hand, yet the machine-made pot, when put to the test of practical work, has, in all cases, failed much more rapidly than the one made by hand.

The mode of manufacture is as follows:—The pot-maker has a slab of stone before him, slightly larger in diameter than the bottom of the finished pot. Upon this stone a thin layer of sand is first spread, to prevent the clay of which the pot is to be made adhering to the stone; then, commencing at the centre of the slab of stone, and working outwards, a spiral string or cord of clay is laid, the joints of the ring being carefully pressed, or welded together, by the hands of the pot-maker, extreme care being taken that the slab of clay that is thus gradually formed shall be perfectly homogeneous, and that all air shall be expressed from it: after the slab is completed its upper surface is roughened, so that the thickening of the slab, by the ad-

dition of further rings of clay, thoroughly incorporated with the first may be successfully performed. When the first slab has been made of the full diameter, or rather more, of the finished pot, a second slab is commenced on its top; the joints of this, both in itself and with the slab below it, being also carefully kneaded together, the roughening of the upper surface of the first slab assisting this jointing. When the bottom of the pot has been thus made of sufficient thickness, the sides are commenced, and are dealt with in a similar manner, this process being carried on until the pot has reached its full height, the angle which would be formed by the sides with the bottom being well rounded both inside and out. It should have been said that the stone slab upon which the pot is made, is carried upon a central pivot, so that the workman may turn it round to reach any part of the pot as he sits down in front of it, having his tools on one side of him, and the lump of clay from which the pot is made on the other.

Upon referring to the section of the pot shown at fig. 3, it will be seen that a ring recess is formed around its sides, at a little distance above its half height. This recess is for the purpose of receiving the jaws of the tongs, or fork, which is used for handling the pot when hot. It will also be seen how all sharp angles are avoided, in those portions of the pot, which have to be in contact either with the molten metal, or with the fire, and how all sudden increases of section or changes of shape are avoided.

Straight-edges, smoothing-boards, a clay knife, and his hands, are the tools necessary to make a successful pot-maker, and he must, as will have been gathered, exercise a great deal of care and judgment.

Although the pot may, up to this stage of its existence, have survived all dangers, yet evil will overtake it, even now, if it is not henceforth properly treated, for it has still to undergo its most trying ordeals, *i.e.* those of being dried and afterwards burnt.

The pot upon its slab is placed on one side in a warm

room kept at a regular temperature, usually by means of steam-pipes placed around it. Variations in the temperature of the room in which it is dried cause unequal contraction in the pot and are usually fatal to its prolonged life. In this warm drying-room it is allowed to remain for from nine to twelve months, a longer time than this being allowed, if the exigencies of the glass manufacture will allow of it. If the pot is now examined a considerable contraction of all its parts will be found to have taken place, and if properly dry it will be perfectly symmetrical in shape and will "ring" as a bell would, on being struck. From this drying-room the pots are taken to a "pot arch" or furnace, where they are burnt, and here they are allowed to remain for so long a time as is necessary to completely bake them, usually from seven to nine days, the heat of the furnace being very gradually raised from cold, after the pots are put in, until it exceeds that of the melting furnace itself.

The pots being now satisfactorily completed, they are removed singly from the pot arch, and being partially filled, while still hot, with the carefully ground and sifted materials of which the glass is to be formed, with a proper proportion of "cullet" added, each of them is put as rapidly as possible, so that it may not cool. into the melting furnace. When the first portion of the materials is melted, a further quantity is added, until a potful of glass is obtained, this is then subjected to the heat of the melting furnace, for such time as is necessary to completely reduce it.

The pot arch, and the melting furnace, are similar in construction. Furnaces for glass melting have already been described in the earlier portions of this book, see pages 35 to 43. In all well-constructed works in modern times these furnaces are heated by Siemens' regenerative or other gas furnaces. A description of a Siemens' furnace with an illustrative diagram has also been given, see pages 110 and 111.

In a plate-glass furnace the pots are placed in two rows, one near each side of the furnace, which consists of a long

arched chamber, built in fire-brick and fire-clay. Doorways closed by doors made of fire-clay tiles fixed in cast-iron frames are situated at each side of the furnace throughout its whole length, each of these doorways being just sufficiently large to allow of a pot being readily removed through it. Sight-holes are provided so that the state of the contents of the pots may be examined, and dampers in the flues and in the furnace, are so arranged that the heat in any part may be increased or decreased at will. Upon its being ascertained that the contents of a pot are melted, and are ready for casting, a door is removed from the side of the furnace, by means of a long fork, or pair of tongs, carried at about the centre of its length upon a pair of wheels, the outer end having a T-head at which the workmen stand to handle the tongs. The door being placed on one side, a fork also upon a pair of wheels, being similarly handled, and having the distance between its jaws just sufficient to enable it to pass around the pot (into the ring recess formed in the pot to receive it, which has already been mentioned), is inserted in the furnace. The workmen bear on the outer end of the fork, the axle of the wheels acting as a fulcrum—they lift the pot, draw it back, and place it upon a low truck upon which it may be taken to the casting-table.

The casting hall, or room, in which the glass is cast, usually has on each side of it the annealing ovens, which are heated in some cases by the waste heat from the melting furnaces and pot arches, but generally each oven is heated by its own furnace. The casting-table is commonly supported on wheels running on a line of rails down the centre of the hall and between the mouths of the ovens. The table having been placed opposite the ends of two of these ovens, one on each side of the hall, and all being ready for casting, a pot with its contents is removed from the melting furnace, placed upon the truck, and taken to the casting-table. From the truck it is lifted by a crane, and being held over one end of the table, it is tilted, and its contents poured in a mass on to the top of the table. A cast-iron

roller turned parallel, and smooth, is then passed backwards and forwards at a uniform speed over the plate, the thickness to which the plate is rolled being regulated by strips of iron placed upon the table, upon which strips the ends of the roller bears, the distance apart of these strips determining the width of the plate of glass. The door of the annealing oven being then opened, the plate of glass is thrust forward into it, the door closed, and the plate of glass left to anneal. All the operations of casting are performed with the greatest rapidity, so that the plate of glass may be as hot as possible when it is placed in the annealing oven; as should it be allowed to cool to too great an extent before annealing, flaws and cracks would be formed, and the plate would most likely, to a large extent, be rendered useless.

Casting tables are made, as has already been stated, of plates of cast-iron. These tables are usually about thirty feet in length, and from ten to twenty feet in breadth. The roller is also of cast-iron, is turned smooth and parallel, is usually about 2 feet in diameter, and is as long as the full width of the table, having chain or rope tackle attached to its ends, by which it can be moved backwards and forwards over the glass to flatten or roll it.

Although the surface of the casting table is planed smooth and true, and although the surface of the roller is turned smooth, and although it is parallel, yet the plate of glass, after annealing, has its surfaces full of undulations or pits—in fact, is in the state of rough plate—and does not present that brilliantly smooth appearance, which is the characteristic of polished plate glass. Many theories have been advanced, as to the causes which produce these rough semi-opaque surfaces. It is now generally conceded, however, that they are due to the fact, that glass being such an extremely bad conductor of heat, the exterior portions of the plate are cooled by contact with the air, and with the metal of the table and of the roller, much more rapidly than the interior portions, and, as a

result of the unequal contraction thus produced, the rough semi-opaque surfaces are formed.

It will be seen, further on in this description of the manufacture of plate glass, what an extremely beneficial effect it would have upon that manufacture, if some means could be devised, by which, after the plate of glass was annealed, its surfaces should at least be smooth.

In addition to the irregularities of surface caused by unequal cooling, it was found some few years ago that the casting tables being composed of, at most, from two to three slabs, or plates, of metal, carefully jointed and bolted together—their upper faces being afterwards planed smooth and true—these upper faces expanded, owing to being heated by contact with the glass in casting, while the lower thickness did not expand, being kept cool by contact with the air; the table, therefore, assumed a bowed form, so that when the plate of glass was ready to be put into the annealing oven, at which time it has often cooled sufficiently to have a definite shape, it had assumed the bowed form of the table.

To bring a plate of glass cast on such a table to a perfectly smooth and level surface, it was necessary therefore, that a large proportion of the thickness of the plate, should be ground away.

This difficulty of the bowing of the plate has in a great measure been overcome by making the table of a number of pieces, thus allowing to some extent for the expansion of the metal of which it is composed, as each piece being so much smaller the bowing of it is so much less, and it does not affect its neighbour. This may be best illustrated by a comparison of the two diagrams, figs. 4 and 5.

Fig. 4 represents the line of the upper surface of a table made in one piece in length, the space between the curved lines representing the plate of glass when cast upon it, and the bowing caused by the expansion being exaggerated in order to show it more clearly. Fig. 5 shows the line of the upper surface of a table of the same length, but made in

six pieces, the bowing being the same in proportion as that shown in fig. 4. In the case of a plate of glass cast on a table made as in fig. 4, in order to bring the surfaces of the plate perfectly true and parallel, the whole of the thickness of the plate except that between the dotted lines x and y would have to be ground away. In the case of a plate of glass cast on a table made as in fig. 5, however, there would only need to be a thickness equal to the distance between the curved lines and the dotted lines a a and b b ground off each side. From this reasoning it appears

Fig.4.
Casting Table in one piece.

Fig.5.
Casting Table in six pieces.

that it would be wise to make the table of a very large number of pieces, but for convenience of construction, this number is limited.

It has been suggested that if the tables were made of some material which is as bad a conductor of heat as the glass itself, the difficulty of the differences of expansion would be, to a great extent, overcome. It has also been suggested that if the surfaces of the table and of the roller could be heated to a temperature approaching that of the glass, the cooling would not be so sudden, and therefore not only would the difficulty of unequal expansion of the table be at an end, but the contraction of the surfaces of the plate of glass would not be so rapid, and, therefore, the irregularities of those surfaces after annealing would not be so great as they now are.

Experiments in these directions have been tried, but

they have not met with the success which it appears at first sight should attend them, and, as before stated, all modern casting tables are made of a large number of plates of cast-iron, carefully jointed and bolted together, and having their upper face planed true and smooth, thus conquering to a great extent the trouble caused by the bowing from unequal expansion of the table, but leaving untouched the questions of irregularity and opacity of surface of the plate of glass after casting.

The annealing ovens are large shallow brick chambers, in which the glass is placed on a "flat" of brickwork, which is heated when the glass is first put into the oven to a temperature approaching or even exceeding that of the glass itself. As already noted, it is of importance that the plates or sheets of glass should be made of as large a size as possible. A large amount of floor space is therefore required for these ovens, as it is impossible either to pack the sheets of glass one on the other, or on edge; if the former plan were attempted it would be necessary to interpose something between the plates, or they would, at the heat at which they are put into the oven, adhere the one to the other, and if the latter plan were tried, they would be found incapable of sustaining their own weight until they had cooled.

In years gone by, the glass was allowed to remain in these ovens, for as long a time as a fortnight, or even more, this time being needed to allow the oven to cool, without external assistance, after it had been heated sufficiently for the reception of the glass. A great improvement was effected, when the arrangement of the ovens was modified, so that currents of air could be passed under the flat of brickwork, and thereby cool it—and the glass upon it. By this means the output from an equal area of floor space, devoted to annealing, was increased more than three-fold, the time required for annealing a plate in an oven as now arranged being only about four days.

After the glass has cooled, it is removed from the oven,

and it will then be found that its surfaces, especially the one which has been uppermost in the annealing oven, are full of undulations, and are semi-opaque. This is, as has already been said, partly due to the devitrification of those surfaces, and partly to the unequal contraction which takes place in the cooling of the plate.

Glass which has only been subjected to the operations hitherto described is called "rough plate."

When the plates have arrived at this stage of their manufacture they are carefully examined, and those which from any cause are imperfect, are rejected. In some cases those portions of some of the plates which contain flaws, but which in all other respects are perfect, are cut out and the perfect portions and the remaining plates are taken to the grinding room, in which room the roughnesses of the surfaces of the glass are mechanically removed.

The machine originally used for this purpose was one known as a "fly frame" machine (a plan of which is shown in fig. 6), the design of which is attributed to James Watt. It consisted of two beds of stone, or planed cast-iron, A A, placed some little distance apart, and upon these the plates of glass to be ground were secured, by being bedded in plaster of Paris. Between the two tables a vertical shaft, C, revolved, having upon it, and working from it by means of a crank, placed just above the level of the beds, a square "fly frame," B B, this frame being anchored to a fixed disc by four radius rods. Projecting over the tables on each side of this square frame, and rigidly fixed to it, were two arms slotted throughout the whole of that part of their length which was over the table. In these slots worked the pins of two large flat cast-iron rubbing plates, D D, the lower surfaces of these plates being in contact with the upper surfaces of the plates of glass. When the vertical shaft was set in revolution, it caused the fly frame with its arms, and, therefore, the rubbing plates, which were pivoted in these arms, to have a curvilinear motion, compounded of the

revolution of the rubbing plate round about its pivot, and of the elliptical motion of the pivot itself. Sand and water being interposed between the surfaces of the rubbing plate and the surfaces of the plates of glass, these latter had their irregularities or undulations gradually ground away. Great improvements were made upon this machine; and at the Ravenhead Plate Glass Works, the machine now to be described (for plan of which see fig. 7), the invention of Mr. Daglish, was adopted.

As will have been seen from the description of the "fly frame" machine, the grinding action was obtained in it, by causing the rubbing plates to traverse the surface of the glass. In Mr. Daglish's machine, however, both the glass and the rubbing plates are moved the one upon the other while they are in contact. His machine consists essentially of a flat table, A, supported on a vertical revolving shaft, B. Upon the top of this table the glass plates are bedded,

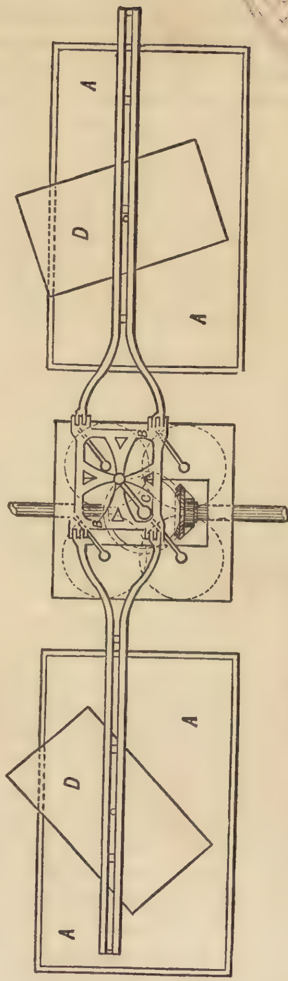


Fig. 6. FLY-FRAME GRINDING MACHINE.

and the cast-iron rubbing plates, C C, which are similar to those used in the old fly-frame machine, are laid upon the glass, and each have a central pivot or pin, D D, which works in the eyes of two fixed radius rods, E E, carried to the outside of the line of revolution of the table, and supported there in cast-iron pillars. The ends of these rods, which are

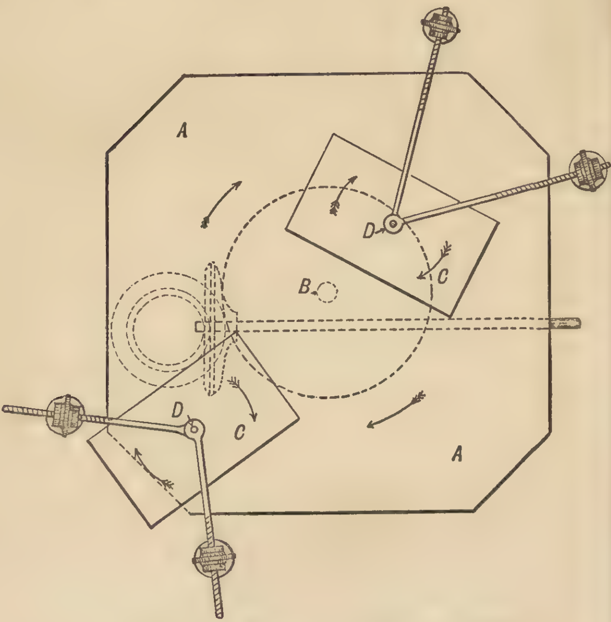


Fig. 7. *IMPROVED GRINDING MACHINE.*

in the pillars, are secured in hand-wheels which have their bosses screwed to form nuts; by turning these wheels, the rods are moved endways, and the distance of the centres of the cast-iron rubbing plates, from the centre of revolution of the table can be varied, and the whole surface of the glass which is bedded upon the table can thus

be subjected to the action of the rubbing plates. Sand and water are used in this machine, as in the old "fly frame" machine, for the preliminary process of grinding.

The sand used in grinding must be clean and sharp. If it is dirty, its action upon the glass is impeded by the clogging of the particles. It should also be of uniform size in grain, otherwise the glass will be scratched by the larger grains, and the operation of grinding will be prolonged.

To insure that it is both clean, and uniform in grain, this sand is carefully washed and cleansed before it is used in the machine. The operation of washing is performed as follows:—The sand being shovelled by hand, under a stream of water, flowing into a trough placed at an angle, is carried by the water down this trough; the lower portion of the trough is made as a sieve, having its meshes of such a degree of fineness as to allow all the sand of a certain size of grain, and, of course, the water to pass through it into a tank placed below; those portions which are too large to pass through the meshes of the sieve falling over its lower end clear of the tank into a barrow placed to receive them. In this tank the sand and water are kept continually stirred, either by hand or by a mechanical stirrer, the sand cleansed of its impurities falling to the bottom of the tank, and the water with the earthy matter overflowing a lip in one side of the tank into a drain, and so away. The apparatus is so arranged that the water and sand, can be caused to flow over either one of two inclined sieves, each placed over its own tank, so that when one tank becomes full of sand, the operations can be carried on in the other, while the first is being emptied.

After the greater portion of the rough surface of the glass, has been removed by the sand, powdered emery-stone of the coarser sorts, is used with water, in this same machine to complete the grinding.

Emery-stone is one of the hardest and most refractory of materials; it is obtained in large quantities from Turkey

and from America. The first crushing or breaking of the emery-stone was originally, and is now usually, done in a Blake crusher similar to that already described. In former times great difficulty was experienced, not only in pulverizing the stone after it had passed through the Blake crusher, but also in separating the finer from the coarser portions of the powder, obtained by the pulverizing. This separation was originally performed by sifting, the powder being passed over a succession of sieves, each having a mesh of a different size. The first sieve removing the finest portion, and the next sieve the next finest, and so on. A great deal of power was required to work these sieves, and numerous troubles were experienced. After very little use the sieves became choked, and would not allow the particles of emery to pass through them; they were also very rapidly worn away by the action of the emery-powder upon them, and the attrition of the particles of emery-powder, the one against the other in sifting to some extent destroyed the sharpness of these particles and their power of cutting. Again, the most valuable part of the emery is the dust or impalpable powder; this, in the grinding and subsequent sifting, was carried away in great quantities by the currents of air raised by the moving machinery, and was lost. In addition to these disadvantages, some of the finer portions of the emery when pulverized, clogged together, and impeded the action of the edge-runners in which the pulverizing was performed.

A great advance in the separation of the qualities of the emery was made when an apparatus was adopted, utilizing the evil of the loss occasioned by the currents of air, and applying the principle embodied in that evil. In this mode of separation, a current of air, was passed through the emery, as it was being ground in the Edge runners. This current was led from the machine along a closed trunk, with the result that, as soon as any portion of the emery had been powdered sufficiently, it was carried away along the trunk by the current of air. The bottom of

the trunk was divided by partitions into some four or five compartments; and it was found that, according to the size of the particles of emery-powder taken up by the current, they would be deposited in one or other of these compartments; the larger the particle, the nearer it would be to the pulverizing machine; and the smaller the particle, the farther away it would be. This was a vast improvement on the method of grinding and sorting hitherto in use: it not only sorted the powdered emery into several qualities, or degrees of fineness, but it kept the machine in which the emery was ground free of the powder, and therefore free from clogging, and it also produced a sharper and cleaner powder. Even this mode of separation, however, had its faults; its sorting was by no means perfect, and it often happened that a particle of emery of larger size than it should be, being from a lighter sample of stone, was carried into a compartment intended for a finer quality; and as the rapidity and success of the final grinding of the plates of glass, and of their smoothing, depends in a great measure upon each different quality of emery being of an equal degree of fineness, this fault was an important one. To obviate these difficulties the apparatus now in use was adopted; it is one which utilizes the principle contained in the separation by an air current, but does so in a more perfect manner.

In this mode of separation, a stream of water, instead of a current of air, is passed through the edge-runners whilst the pulverizing is being done. Several advantages accrue from this. For example, the work of grinding is rendered much less injurious to the health of the workmen, for in the operation of grinding "dry," the finest portion of the powder produced permeates the atmosphere of the grinding-room, and is, of course, inhaled by the men; again, the stream of water acting more efficiently than the current of air in removing the powder as it is produced, the duty performed by the edge-runners is greater. But the emery-powder being now mixed with water, the question arises,

How is this powder to be accurately separated into its various degrees of fineness? This is done in the most beautiful, perfect, and yet simple manner, and in the very process of sorting, the earthy matter or impurities contained in the emery-powder are removed, an advantage which was not obtained by either of the modes of separation hitherto described. For each size of grain into which it is wished to separate the ground emery-powder, an open-topped vessel is provided. The stream of water, carrying with it the emery-powder as it leaves the edge-runners, is passed through a pipe, and falls into the first open-topped vessel, through a central funnel long enough to reach to within, say, some three inches of the bottom of the vessel; an additional supply of water being poured into the funnel in a constant stream (which can be regulated) from a cistern placed above the open-topped vessel, the water and emery-powder descend through this funnel to the bottom of the vessel, the coarser portion of the emery powder is deposited in this vessel, the remainder is carried by the stream of water up the annular space round about the funnel and in the vessel, and flows through a spout at its top into the funnel of a second open-topped vessel of greater capacity than the first, and placed at a slightly lower level; the funnel of this second vessel has another stream of water pouring into it from the cistern which supplies the first vessel. Here the second quality of powder will be deposited, the water introduced from the cistern, and the emery-powder and water from the first vessel, passing up the outside of the funnel in this second vessel, and flowing through a spout into a third funnel of a third vessel, and so on. The area, or rather the cubical contents of these vessels, is increased in succession—that is to say, No. 1 is the smallest, and in this the coarsest quality of the emery will be found; and No. 2 is, say, twice the capacity of No. 1, No. 3 twice that of No. 2, and so on.

As these vessels are of increasing capacities, the speed at which the current of water flows through and out of

them, is less in each of the vessels, and therefore the portions of emery of different size, and therefore of different weight, are carried to a less and less distance from the original source of supply. In addition to this the stream of fresh water which flows into each of the funnels can be regulated, and thus the total strength of the current can be increased at will for any vessel, so ensuring a more complete separation of the various degrees of fineness of the emery powder. The principle upon which this separation is based is naturally illustrated in the case of a river flowing into a lake, where it will be seen that the larger portions of the detritus brought down by the river are deposited near its entrance into the lake, where the current of the river has the greatest effect, and the smaller portions are carried by the decreasing force of the stream farther out into the lake.

In the bottoms of the open-topped vessels plugs or valves are placed, so that when it is found that the water and emery in flowing through the funnel, and up the annular space, has deposited the emery-powder in such quantities, as to cause it to rise nearly to the level of the bottom of the funnel, the inflow is stopped, and the plug removed, or the valve lifted, and the emery-powder allowed to run out into a vessel placed to receive it; then the stream of emery and water is again turned on, and the operation repeated.

By this apparatus, the most perfect separation of the powder is obtained without causing any dust, any loss of that which is the most valuable part of the powder, namely, the finest portion, or any ill effects upon the workmen; the whole process is cleanly, the apparatus is small, and requires no power to work it, except that necessary to raise the water to the required height (some two or three feet) above the level of the first open-topped vessel; as has already been suggested, another great advantage, which accrues from the use of this mode of separation, is that the emery-powder is thoroughly washed, and the impurities and earthy matter

which are in the emery-stone pass away with the dirty water from the last of the open-topped vessels in a similar manner to that in which they pass away in the operation of sand washing already referred to. The various degrees of fineness of the emery-powder, after being removed from the separating apparatus, are placed in vessels provided with gauze-wire bottoms, and the surplus water is allowed to drain away. Of course it will be seen that no difficulty arises in consequence of the emery powder being wet, as water has to be mixed with it before it can be used. A somewhat similar mode of separation and washing has been for many years in use in the manufacture of "whitening."

It is found, that the sand which has been once employed in the grinding, has still a great deal of work, or power of cutting, left in it, after it has passed away from the grinding-machine, and it is customary to again use this sand. The water and sand flow in a stream into drains placed below the tables of the grinding-machines; this stream passes through these drains into a large tank placed to receive it, the water flowing through a spout over the top of the tank, and so away, the sand falling to the bottom and being left in the tank. The emery-powder and water also pass from the machine through these drains into the same tank. When the tank is full of sand and emery powder, these are taken out and again used in the grinding machine.

After the glass has had one of its roughened surfaces removed in the grinding-machine by the use of the sand, and then by the use of the coarsest descriptions of emery, the plates of glass are turned over, and the operation repeated upon the other surface. Finally, before leaving the grinding-room, the glass is again carefully examined for flaws, and is sorted, such portions as may be faulty being cut out of the plate and thrown to waste.

The next operation which the glass has to undergo is that of smoothing; this is performed by machine in the smoothing-room, and here the "ground" or semi-opaque

surfaces which have been left upon the plate by the grinding-machine, are removed by the application of the finer sorts of emery with water, in a machine known as a smoothing-machine.

The smoothing-machine at present in use (for plan see fig. 8) is a modification of the old "fly-frame" grinding-machine. Instead of cast-iron rubbing-plates being employed, how-

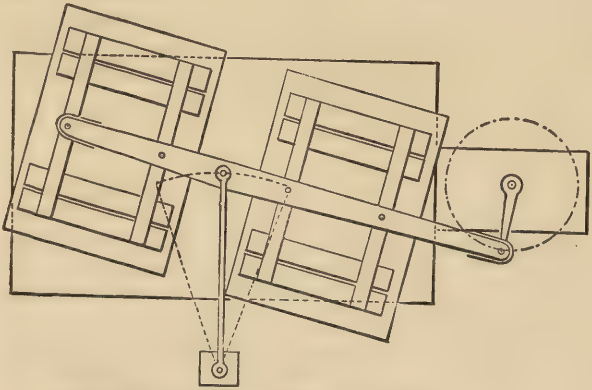


Fig. 8. *PLAN OF SMOOTHING MACHINE.*

ever, one sheet of glass is used to rub upon another, the upper sheets which are the moveable ones being weighted. In the smoothing-machine there is only one table, which is either of stone or of cast-iron, and upon which the glass is bedded; then another sheet of glass being placed on it and weighted, an arm moved by a crank fixed on a vertical revolving shaft placed at the end of the table, the arm being anchored, by a radius rod, to a pillar at the side of the table, is set in motion, and a rubbing action ensues between the two plates of glass.

Emery-powder of the finer descriptions, commencing at the coarsest of these, and water, is used in this smoothing; the final operation and the removal of any minute scratches

which may be caused in the smoothing in this machine, being afterwards done by hand, wood blocks, and "flour-emery" or the very finest powder from the emery stone, and water being used for this purpose.

It is found to be absolutely essential that this final operation of smoothing, should be performed by hand, as the smallest portion of "grit" in the emery can be readily discovered by a practised hand, whereas if mechanical power were employed, scratches would frequently be made before the grit was observed. In order to readily discover any grit, and so that imperfections of any sort in the glass shall be readily seen, it is essential that this room should be well lighted. In the smoothing-room the work is most frequently performed by women.

After the completion of the smoothing operation the plates of glass are again carefully examined, and are then taken to the polishing-room, there to undergo the final operation of polishing, this being effected by the interposition of "rouge" or "red oxide" and water, between moving pads of felt and the surface of the glass.

The machine in use for polishing the glass is practically that originally designed for the purpose; it is not only used in plate-glass works, but is the machine used for polishing that description of glass which is known as "patent plate." It consists of a perfectly true and level table upon which the glass to be polished is bedded in plaster of Paris; this table has an alternating side-way motion at a slow speed, under a pair of arms having a rectilinear motion at a high speed at right angles to that of the table, this rectilinear motion being communicated by means of cranks and connecting rods, from a horizontal revolving shaft placed at one end of the table. Upon the arms, and at intervals of about every twelve inches, weighted spindles are placed, each having at its bottom end a disc of wood, capped with felt, the felt being in contact with the surface of the glass, which is bedded on the table. "Rouge" or "red oxide" (oxide of iron) and water are applied to the glass, and the

glass is allowed to remain upon this machine until all the scratches are completely removed from its surface and until it is polished.

The rouge used in this operation is prepared from that which is known technically as "green copperas," or chemically as sulphate of iron or ferric sulphate. This is burnt to a white heat, for some 36 hours, in a furnace heated by a Siemens' Regenerative Furnace, it is then withdrawn, and is ground in water, the resulting liquid rouge being squirted by syringes on to the face of the glass while the polishing process is going on. Many other materials and powders have been suggested as being superior to rouge for the purpose of this polishing, but none have, so far, been found capable of superseding it in practice, neither have any been found possessing its peculiar advantages, of fineness of cut, evenness of grain, and last, but not least, cheapness of manufacture.

One surface of the glass having been polished in this machine, it is turned over, again bedded, and its opposite surface treated in a similar manner.

Frequent mention has been made of plaster of Paris as being used for bedding the glass upon the tables of the grinding, smoothing, and polishing machines. This material is obtained by burning "gypsum" or limestone, usually in a revolving furnace, the heated gases from a regenerative gas-furnace being passed over the stone. The burnt gypsum is then ground by means of Blake crushers and edge-runners, similar to those already described, so as to pulverize it, and after being carefully sifted, forms the "plaster of Paris" which has been so often referred to. This material when mixed with water, sets very rapidly, and is in this state used to bed or fix the glass upon the surface of the tables. It is thoroughly well adapted for this purpose, as it is cheaply produced, its power of "holding" the glass is ample, it sets extremely rapidly, and does not contract to any great extent in that setting, and when mixed into a cream with water, it is extremely easy to handle and

manipulate. In addition to all these advantages, it can, after having been once used, and when removed from the tables of the machines, be thoroughly dried and re-burnt, and again broken up, sifted, and re-used, its power of rapidly setting not having been reduced except in a very small degree.

Referring again to the question of the "holding" or sticking power of the plaster, it must be remembered that this is due in a great measure to the fact of the air being absent from the under side of the glass, and that therefore the air-pressure is acting with nearly its full force (about 15 lbs. to the square inch) upon the upper surface of the glass, to prevent its moving or slipping upon the plaster or in other words upon the bed of the machine.

After the glass has been completed in the polishing-room, it is in that perfect state when it is known as polished plate glass. It then presents a beautiful, brilliant, and even surface, and if of perfect manufacture should be absolutely transparent.

From the polishing-room it is taken into a warehouse, where it is sorted into sheets of the different thicknesses and qualities, and where it is cut up to any size which may be required.

It has often been a matter of surprise and wonder how sheets of glass of the great thickness of plate glass when finished (say from three-eighths to five-eighths of an inch) can be readily and truly cut; but if a little thought is expended on the subject, it will be seen that the material "glass" is of such an inherently brittle nature that, given a "line of fracture" or a "weakest part" and a strain upon the glass, it must inevitably break along that line of fracture or weakest part. Thus it is that, as with ordinary crown glass, so with plate glass, the mere scratch upon the surface occasioned by passing a diamond over it offers that "line of fracture" or "weakest part," and a slight strain put upon the plate in the proper direction will cause it to split truly and evenly along that line.

In the packing warehouse the cutters may be seen at work; and although from what has been said above, it may appear that the operation of cutting is a simple and easy one to perform, yet great skill and experience are absolutely essential in dealing with sheets of the largest size, say from twelve to fifteen feet long and from eight to ten feet broad; for if, after the glass has been subjected to the various operations described, and a plate perfect in every respect has been produced, it should be destroyed through carelessness in this the final operation, a large monetary loss would be occasioned, and the result of weeks of labour would be rendered commercially useless.

APPENDIX A.

EXAMINATION PAPERS.

THE following are the examination papers in the Technology of Glass Manufacture which have been set in the examinations of the City and Guilds Institute. Previous to the transfer of these examinations from the Society of Arts to the Institute, no paper in this subject was set.

1880.

Examiner:—J. Pellatt Rickman, Esq.

ELEMENTARY.

1. What are the essential and distinguishing qualities of good flint glass?

2. What ingredients are *necessary* to form glass, and what are added for the finer qualities?

3. Give the usual mixtures for (*a*) crown glass, (*b*) plate glass, (*c*) bottle glass, (*d*) flint glass?

4. Describe the various forms of pots used for melting the several descriptions of glass, and state why each is so used.

5. Describe the making of a soda-water bottle, a claret jug, and a barometer tube.

6. State the action of the ordinary annealing process, and fully describe the "lear" and "kiln," and state for what class of work they are respectively most suited.

7. In what respect is glass improved by being laded into cold water?

8. In what respect is "laded" metal superior to that which is gathered?

9. What is the effect produced upon flint glass by the addition of manganese, of borax, and of arsenic?

10. What are the usual colouring matters used in glass-making, and what colours do they respectively produce?

11. Describe the most modern form of press, and the process of pressing a tumbler and a raised dish.

ADVANCED.

1. What is the specific gravity of English flint glass of the first quality, and state by which of its ingredients this is principally regulated?

2. What is meant by "the crisis" in founding glass?

3. Describe fully the Siemens furnace as applied to melting in pots, and in tanks; and any other special form of furnace with which you are acquainted.

4. How does the system of working in a "bottle house" differ from that of a "flint house?"

5. In what does the French system of working in a flint house differ from the English? To which do you give the preference, and why?

6. What are the special characteristics of the "Prince Rupert's drop?"

7. Fully describe M. de la Bastie's hardening or toughening process, and state the difference in the constitution of glass which has undergone this process, and that which has been annealed in the ordinary way.

8. What is meant by "devitrification?" How is it caused, and in what forms of glass is it most common?

9. How is English ruby glass made, and how worked?

10. What was the colouring matter in ancient ruby glass, and in what class of work is this now most nearly imitated?

Honours.

1. Describe the several "cutting" processes and the necessary tools.

2. Describe the process of "engraving."

3. Describe the process of "etching."

4. Describe the process of "printing."

5. Describe the process of pouring, rolling, and polishing plate glass.

6. Describe the manufacture of the Venetian filigree and mille-fiore work.

7. What is the constitution of the German hard glass used for chemical apparatus, and why is it not made in this country?

8. Which do you consider to be superior, English or foreign table glass? and state your reasons.

9. Why is it that both French and German manufacturers are able to produce articles of medium and common quality at a much lower cost than can be done in English?

10. Have you any scheme by which this state of affairs may be reversed?

1881.

Examiner:—J. Pellatt Rickman, Esq.

Elementary.

1. What is flint glass, and why is it so called?

2. In what respect do plate and crown glass differ from flint glass, and of what are they respectively composed?

3. Give receipt for making green and black bottle glass.

4. What effect is produced by an excess of soda or common alkali in flint glass?

5. Give receipts for blue, green, topaz, and opal.

6. In making coloured glasses for working with flint or

with one another, what is the essential condition to be attained, and why?

7. What is meant by "casing," and why is ruby glass always so used?

8. Why is the German ruby cheaper than the English? How are they respectively prepared?

9. What is meant by the terms "high and low" as to colour, and how can a defect in either direction be corrected?

10. Describe fully the making of the articles with which you are best acquainted.

Advanced.

11. What is meant by "striæ," and how they are to be avoided?

12. What object is attained by the process known as "dragging?"

13. Describe the manufacture of glass for optic purposes.

14. Why are open pots preferred to closed ones for founding metal in this country, and how do the continental makers succeed in making really good metal in open pots?

15. Describe the various forms of tanks used in bottle making.

16. In what respects is the Siemens furnace superior to those of the old type?

17. What form of furnace do you consider will turn out the largest quantity of good flint metal for a week's work?

18. In what consists good annealing, and why is it necessary in all kinds of glass?

19. Give a simple proof that annealing materially increases the homogeneity of glass.

20. Why have not any of the "toughening processes" been permanently adopted in the trade?

Honours.

21. Describe the process of Siemens and De la Bastie.

22. Fully describe the process of "cutting."

23. Fully describe the process of "etching" and the machines used.

24. Describe the sand blast process and the machines used.

25. Describe the process of making common window glass.

26. Describe the method of using wooden moulds employed upon the Continent, and state why they are not adopted in this country.

27. Fully describe the various modes of working in a glass house which are employed upon the Continent, and suggest which of them could with advantage be imported into this country with a view of lessening the cost of production.

1882.

Examiner :—J. Pellatt Rickman, Esq.

Ordinary or Pass Grade.

1. What do we know of the antiquity of glass-making, and to whom is the first making of glass accredited?

2. What is the chemical composition of glass in its simplest form, and of what materials is it necessarily composed?

3. Give the receipts for best flint, plate, sheet, and for green and black bottle glass.

4. In what does metal for "pressing" differ from that for ordinary blown goods? What is the American "lime" glass?

5. Fully describe the furnaces used and the methods of founding the various metals.

6. Upon what does the homogeneity and clearness of the metal depend in founding?

7. What is "batch," and what is the process of "fritting?"

8. Upon which of the first laws of nature do all the glass blowers' operations depend? Give instances.

9. Describe the making of the various articles in glass with which you are best acquainted.

10. What is annealing?

11. In what properties does annealed differ from unannealed glass?

12. Describe the process of "cutting" and "etching" glass.

Honours Grade.

1. What is meant by "devitrification?"

2. Describe "Réaumur's porcelain."

3. What were the probable constituents of the old Roman glass, and how do you account for its frequent crackled and prismatic appearance?

4. How do you account for the change of colour which has taken place in much of the old coloured glass in church windows and elsewhere?

5. Describe the manufacture of the Portland vase. In what do its great merits consist?

6. Describe the form of furnace which you consider will turn out the largest quantity of good flint metal for a week's work, and give reasons for your preference.

7. Describe the manufacture of optic lenses.

8. Describe the making of plate glass.

9. Describe the Continental method of blowing tumblers, &c., in wood moulds, and state why it is not adopted in this country.

10. Why are English manufacturers so slow to adopt the newer forms of furnace now usual on the Continent, and in the United States?

11. How is it that the Continental makers can turn out all classes of table glass so much cheaper than can be done in this country?

APPENDIX B.

LIST OF WORKS RELATING TO GLASS MANUFACTURE.

F. Barff. Glass and Silicates. (Brit. Manufacturing Industries.) 1877.

F. Barff. Silicates, Silicides, Glass and Glass Painting. (Cantor Lectures, Society of Arts.) 1872.

James Ballantine. Treatise on Painted Glass. 1845.

N. E. Beurath. Glas-Fabrikation. Brunswick. 1875.

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Bolley's Technologie. Bd. iii.

G. Bontemps. Examen Historique et Critique des Verres . . . formant la Classe XXIV. de l'Exposition Universelle de 1851. Paris, 1851.

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G. Bontemps. Peinture sur Verre au 19e Siècle. Paris, 1845.

H. Chance. Crown and Sheet Glass. Soc. of Arts Journal, vol. iv. (1856), p. 222.

Achille Deville. Histoire de l'Art de la Verrerie dans l'Antiquité. (Roy. 4to, 112 plates in colours.) Paris, 1873.

M. Faraday. Manufacture of Glass for Optical Purposes. Phil. Trans., vol. cxx. (1830), p. 1.

P. Flamm. Le Verrier au XIXe. Siècle. Paris, 1863.

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A. W. Franks. Book of Ornamental Glazing Quarries. (One hundred and twelve tinted plates of painted glass.) 1849.

E. O. Fromberg. Handbuch der Glasmalerei. Leipsic, 1851.

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M. A. Gessert. Geschichte der Glasmalerei, &c. Stuttgart, 1839.

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